

**U.S. DEPARTMENT OF COMMERCE
National Technical Information Service**

AD-A030 264

High Expansion Foam Extinguishment of Machinery Space Fires

Coast Guard Research and Development Center Groton Conn

Dec 75

275148

Report No. CG-D-83-76

HIGH EXPANSION FOAM EXTINGUISHMENT OF MACHINERY SPACE FIRES

Robert C. Richards



December 1975

Final Report



Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22161

Prepared for
DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D.C. 20590

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

ADA 030264

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report reflect the views of the Coast Guard Research and Development Center, which is responsible for the facts and accuracy of data presented. This report does not constitute a standard, specification or regulation.

Technical Report Documentation Page

1. Report No. CG-D-83-76	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle HIGH EXPANSION FOAM EXTINGUISHMENT OF MACHINERY SPACE FIRES		5. Report Date December 1975	
		6. Performing Organization Code	
7. Author(s) Robert C. Richards		8. Performing Organization Report No. CGR&DC 35/75	
9. Performing Organization Name and Address United States Coast Guard Fire and Safety Test Facility Mobile, Alabama 36615		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Department of Transportation United States Coast Guard Office of Research and Development Washington, DC 20590		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Performed at the U. S. Coast Guard Fire and Safety Test Facility under the technical control of the U. S. Coast Guard Research and Development Center.			
16. Abstract This report details the fire research conducted on board the M/V RHODE ISLAND during the period 10 December 1974 through 17 December 1974. The tests were designed to determine the effects of fill rate, preburn and free venting area on the effectiveness of high expansion foam when used to extinguish machinery space fires. Systems design and agent characteristics were varied in order to determine the optimum and minimum parameters of fire extinguishment. It was shown that high expansion foam could extinguish the fires when applied at a rate of 7 to 9 cubic feet of foam (400-465:1 expansion ratio) per minute per square foot of fire area.			
17. Key Words high expansion foam, machinery space fires, fire extinguishment, ship fires, marine safety		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 62	22. Price 4.50

PREFACE AND ACKNOWLEDGMENTS

This test series is part of a general program of research being undertaken by the U. S. Coast Guard Fire and Safety Test Facility and directed toward full-scale evaluation of possible improvements in ship safety. Guidance in long-range planning of tests to be conducted at the facility is provided by the Ad Hoc Test Advisory Group.

This test program was a joint effort between Mine Safety Appliance Research Corporation and the U. S. Coast Guard. The teamwork exhibited was a credit not only to the individuals involved, but also to their organization. The efforts of Mr. Ralph Hiltz in connection with this test program is especially appreciated. It is hoped that through these efforts, the control of machinery space fires on board merchant vessels may be improved.

ACCESSION for	
NTIS	White Section <input checked="" type="checkbox"/>
DIC	Ref Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
Dist.	Avail. & w/ SPECIAL
A	

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1
1.1 Problem Statement	1
1.2 Program Purpose	1
1.3 Background	2
1.4 Limitations	2
2.0 PROCEDURES	3
2.1 Physical Plant	3
2.2 Instrumentation	3
2.3 Fuel	13
2.4 Ignition Method	13
2.5 Foam System	13
2.6 Test	13
3.0 TEST RESULTS	17
3.1 Test #1	21
3.2 Test #2	25
3.3 Test #3	28
3.4 Test #4	32
3.5 Test #5	35
3.6 Test #6	38
3.7 Test #7	42
3.8 Test #8	45
3.9 Test #9	48
3.10 Discussion of Results	48
4.0 CONCLUSIONS	51
References	55
APPENDIX A - Mechanical Effects on Foam Output by Shielding or Ducting	53

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Page</u>
1. M/V RHODE ISLAND general vessel outline	1
Machinery space profile	2
2. M/V RHODE ISLAND port aspect view	6
3. Machinery space, plan view	7
4. Machinery space, sectional view	9
5. Ventilation duct arrangement, top view	11
6. Performance curves for 600 cfm foam generator	14
7. Typical foam generator installation	16
8. Smoke venting through high-expansion foam generator during preburn	18
9. Machinery space partially filled with high expansion foam	19
10. Test #1 data	22
11. Test #1 data	23
12. Gas analysis, Test #1	24
13. Test #2 data	26
14. Gas analysis, Test #2	27
15. Test #3 data	29
16. Test #3 data	30
17. Gas analysis, Test #3	31
18. Test #4 data	33
19. Gas analysis, Test #4	34
20. Test #5 data	36
21. Gas analysis, Test #5	37
22. Test #6 data	39
23. Test #6 data	40
24. Gas analysis, Test #6	41
25. Test #7 data	43
26. Gas analysis, Test #7	44
27. Test #8 data	46
28. Gas analysis, Test #8	47
29. High expansion foam fill rate	49

LIST OF TABLES

1. Thermocouple locations	12
2. Foam concentrate characteristics	15
3. Test data summary	20

1.0 INTRODUCTION

1.1 Problem Statement

Machinery spaces of ships are a major area of fire potential. A variety of fire suppression mechanisms have been investigated by both the U. S. Coast Guard and the U. S. Navy. High expansion foam has demonstrated potential in the rapid control of fire in confined areas. Fixed foam installations protect warehouses, aircraft hangars, chemical storage and other similar areas. Foam tends not to be used where personnel are involved. Although foam is toxic only when ingested, and one can move through it with minimal breathing problems, it does disorient and hide obstacles, making passage hazardous.

In the case of machinery space fires rapid evacuation occurs in an upward direction. Thus, foam could be delivered without interfering with personnel egress. The ability to totally flood the space with a material 1/500th the density of water and with a proven ability to rapidly control fires involving petroleum products provides strong incentive to evaluate high expansion foam for machinery space fire extinguishment.

High expansion foam is effective against fire in three ways. First, its tremendous volume can prevent air from reaching the fire. Second, a foam containing sufficient water, when driven into the heat of fire, will produce enough steam to reduce the oxygen content of the atmosphere so that active burning ceases. And, finally, a high expansion foam containing a reasonable amount of water can cool and extinguish if the foam is supplied in sufficient volume and is maintained long enough.

The capability of the foam can be affected by a number of variables which are functions of formulation and generation. The primary variables are expansion ratio and drainage characteristics. In general, as the expansion ratio decreases, the drainage characteristics improve. When the drainage characteristics improve (i.e., drainage rate decreases) then the following properties improve: (a) foam flow characteristics, (b) foam collapse rate, (c) resistance to thermal effects, (d) resistance to combustion products, and (e) resistance to mechanical effects.

1.2 Purpose

The primary purposes of this test series were:

- Determine the ability of high expansion foam to extinguish machinery space fires when the foam generators are provided with outside air.

- Determine what influence certain variables, such as fill rates, preburn time, foam expansion ratios, and fire venting areas have on the effectiveness of the agent.

- Investigate the parameters for installation of high expansion foam systems in machinery spaces.

• Provide a basis to compare high expansion foam and other agents as to extinguishment capability in machinery space fires.

1.3 Background

High expansion foam has been accepted nationally and internationally as a suitable extinguishing agent for a variety of envisioned fire conditions. In 1967 the International Maritime Consultative Organization developed guidelines for installation of fire protection equipment on board vessels for protection of machinery spaces. These requirements were based on the best available test data at the time.

More recently, efforts by the U. S. Navy have been directed to self-contained high expansion foam systems operating within the machinery space¹. Testing of the effectiveness of these systems has been conducted by the Navy². In these tests the system was not particularly effective. The primary reason for this was due to the Navy's requirement to use inside air to supply the foam generators. During the fire this inside air becomes laden with soot and particulate matter. This matter in turn causes poor high expansion foam quality primarily because the bubbles tend to coalesce on the soot and particles.

With merchant or noncombatant ships, the inside air requirement is not necessary, and the introduction of foam through fresh air ventilators seems reasonable. Some limited testing under U. S. Coast Guard auspices has been done with foam introduced into the engine space in this manner. Although these tests were relatively unsuccessful, it would appear that the lack of success was due to the mechanical foam generating system rather than failure of the foam itself. To successfully flood the machinery space through the fresh air intakes requires that the foam generator be able to develop sufficient pressure head to push foam down the intake and then force the foam to rise through the space. It is not certain that the generators in prior tests were able to develop a sufficient pressure head.

An additional factor in prior tests may have been the method of installation. The fitting of foam generators into ducts or other openings requires that the opening be a minimum of 30 percent larger than the diameter of the generator screen. Equal or smaller diameters choke the output of the generator. It appears that this also occurred in earlier tests. It is felt that the use of a generator with adequate pressure head, correctly installed, and employing a foam agent reflecting the best in drainage technology can successfully control an engine room fire.

1.4 Limitations

An inherent problem in full-scale fire testing is the inability to exactly duplicate all of the variables which effect the fire. This leads to a lack of duplication of results. The lack of ability to reproduce test results exactly does not diminish the validity of the tests. Every effort was made to accurately control quantity, fire area and application rates. Variables such as humidity,

wind speed, wind direction and initial temperature of the machinery space could not be controlled. However, the author believes that test results reported herein could be repeated to within ± 20 percent, which he considers adequate for tests of this nature.

2.0 TEST PROCEDURES

2.1 Physical Plant

This series of full-scale tests was undertaken at the U. S. Coast Guard Fire and Safety Test Facility in Mobile, Alabama, on board the M/V RHODE ISLAND, an 8,500 gross ton T-1 tanker, moored at the test site at Little Sand Island.

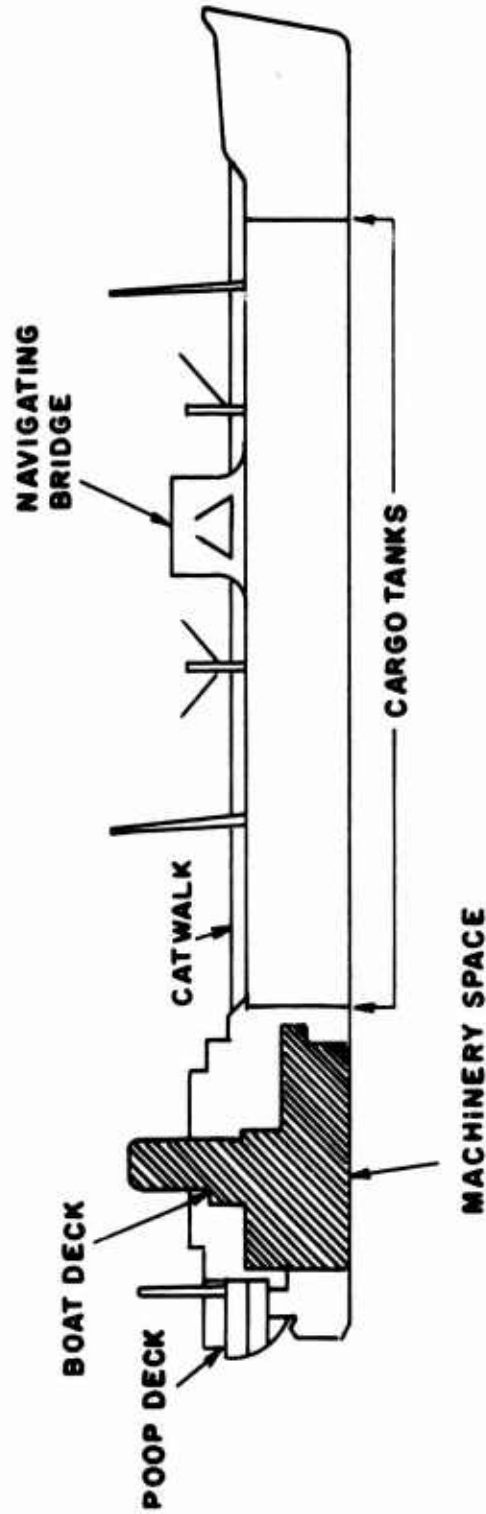
A general outline of the vessel and the machinery space are diagrammed in Figure 1. The port view of the RHODE ISLAND and correlative dock facilities are seen in Figure 2. Figures 3 and 4 show the plan view and sectional view respectively of the machinery space, in which the tests were conducted. The approximate volume of this space is 100,000 cubic feet. It is a multilevel configuration with a total of five internal levels, formed principally by open gratings.

Ventilation for the machinery space is provided by six ducts penetrating vertically through the machinery space casing overhead. The exact location and arrangement of the ventilation ducts are shown in Figure 5. The four electrically driven 37,500-cubic-feet-per-minute fans were added to replace the original equipment at the time the vessel was converted to a fire test platform. They provide a powered fresh air supply through the rectangular 3-foot by 2.5-foot ventilation ducts which open into 4-foot square ducts for the upper 4 feet. Two vents marked "FWD VENT" and "AFT VENT" were installed in the machinery space casing top for these tests. When opened, the forward vent provided provided a vent area of 10 square feet and the after vent an area of 8 square feet.

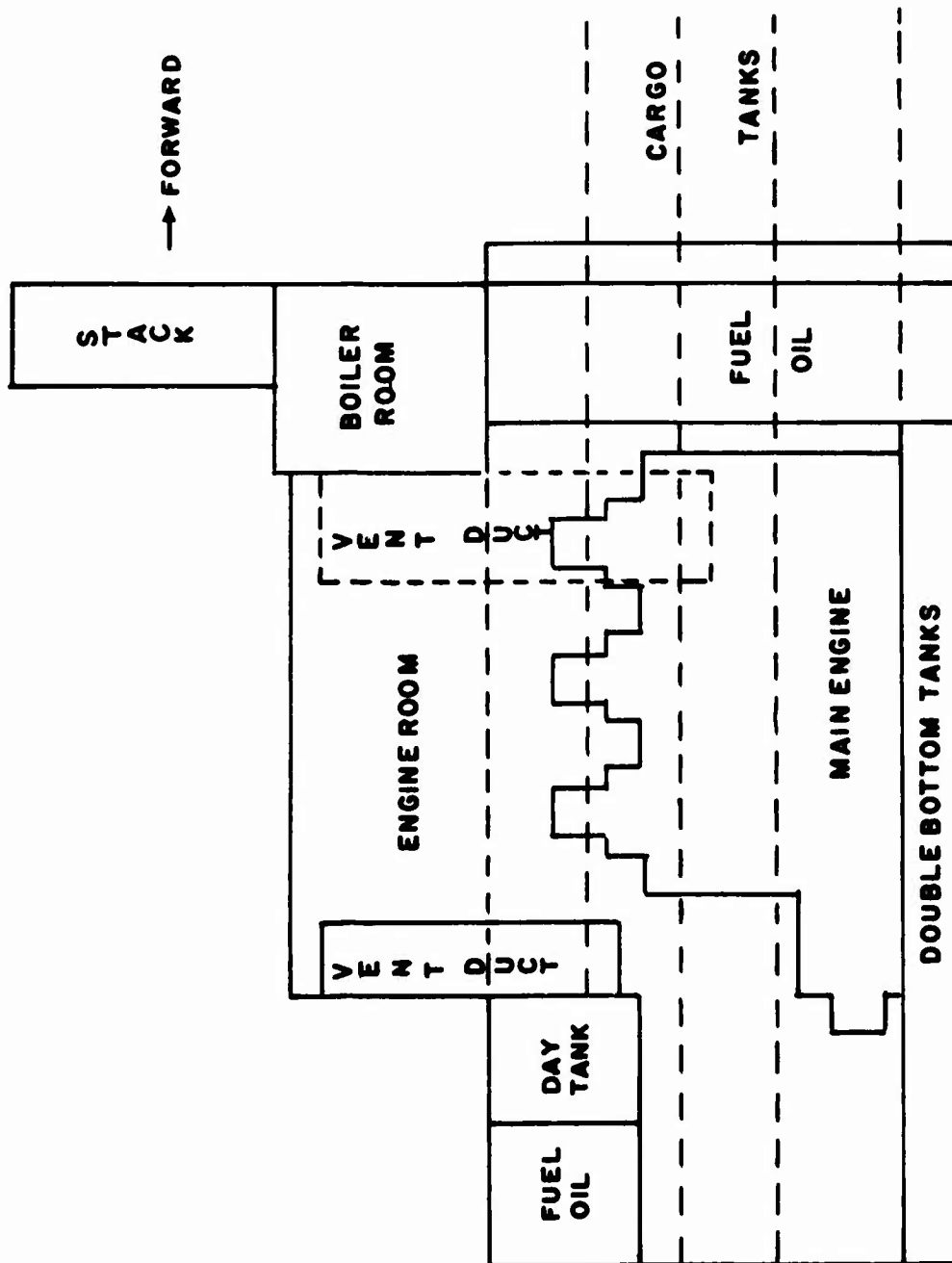
2.2 Instrumentation

Instrumentation was provided to monitor temperature; gas analysis of CO, O₂ and CO₂; wind speed and direction; relative humidity outside the space; and barometric pressure. These transducers were monitored on separate channels of a digital recording device. This device was capable of scanning all 37 channels at a rate of 3 channels per second. Thus a data point was taken approximately every 13 seconds for each transducer installed. These points were then plotted by computer for analysis.

Permanently installed thermocouples (24) were utilized for temperature measurement. These thermocouples were installed in the grid pattern shown in Figures 3 and 4 and listed on Table 1. The gas (CO, O₂, & CO₂) sample locations are also diagrammed in these figures. The probes were mounted two feet below the center of the skylight, and on forward and aft bulkheads at mid-height on the center line of the ship.



M/V RHODE ISLAND
FIGURE 1. GENERAL VESSEL OUTLINE
(SHEET 1 OF 2)



NO SCALE

FIG.1 MACHINERY SPACE PROFILE
(SHEET 2 OF 2)

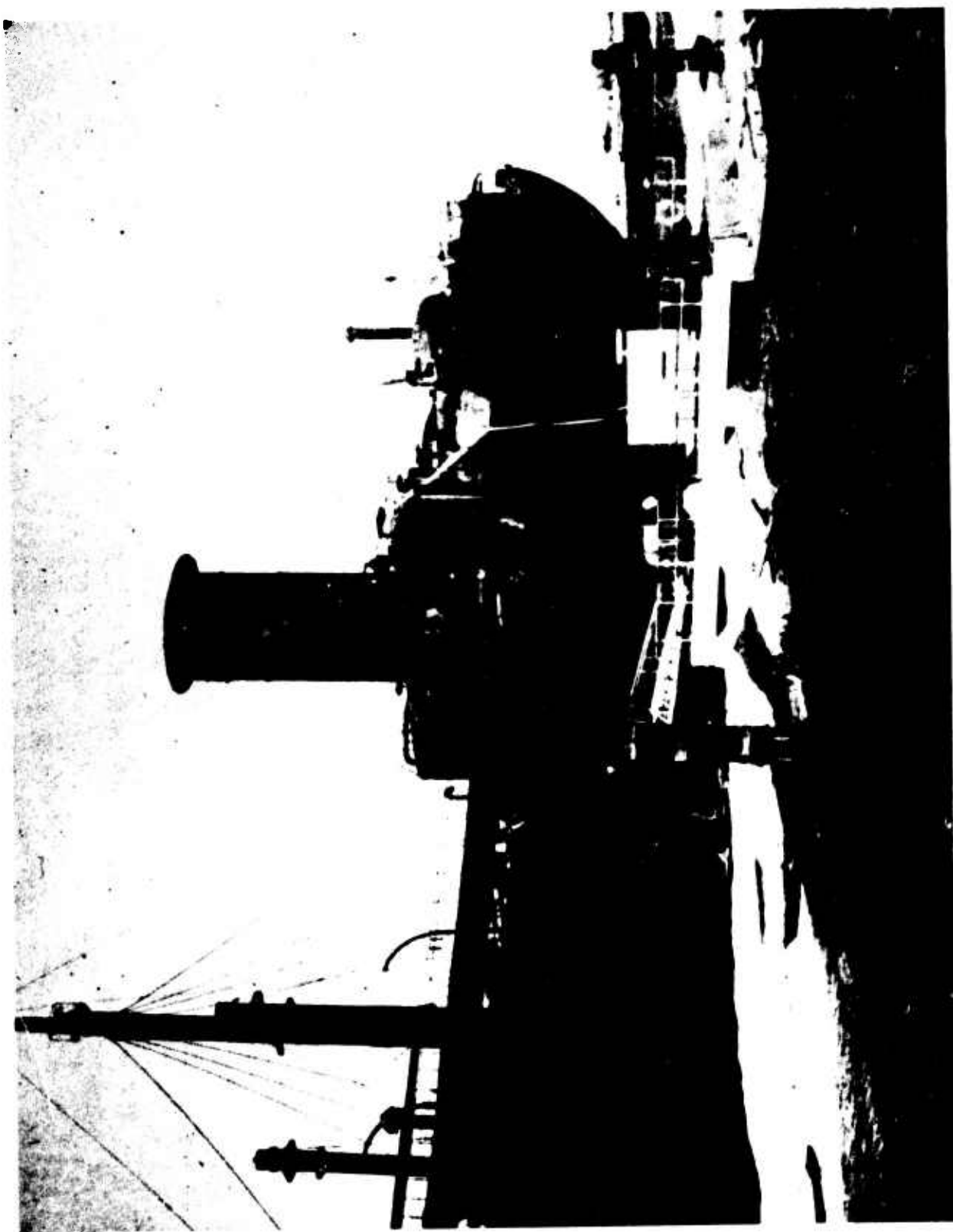
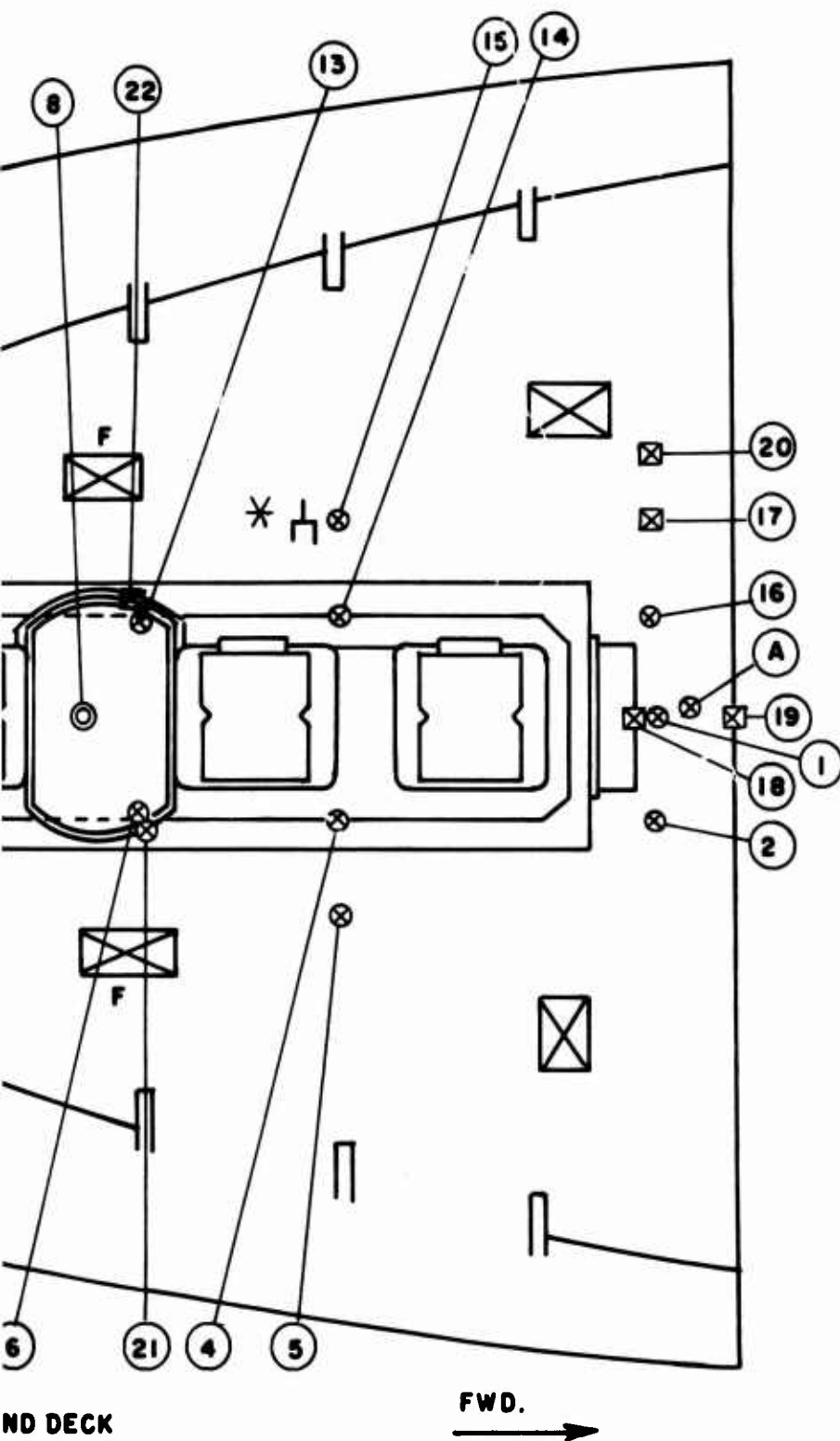


Figure 2. M/V RHODE ISLAND port aspect view.



1



- THERMOCOUPLE NUMBER
- ⊗ THERMOCOUPLES IN AIR
- ⊠ THERMOCOUPLES IN METAL
- * IGNITION POINT

- ⊠ VENTILATION DUCT
- F HIGH EXPLOSION FOAM SUPPLY SYSTEM

- ⊙ OXYGEN, CARBON MONOXIDE SAMPLER LOCATIONS

- ┐ OIL SPRAY LOCATION

NOTE : THERMOCOUPLES 19, 20, 21, & 22 ARE LOCATED 20 FEET ABOVE ENGINE ROOM FLOOR, OTHERS (EXCEPT NO. 3, 17 & 23) ARE LOCATED 8 FEET ABOVE FLOOR.

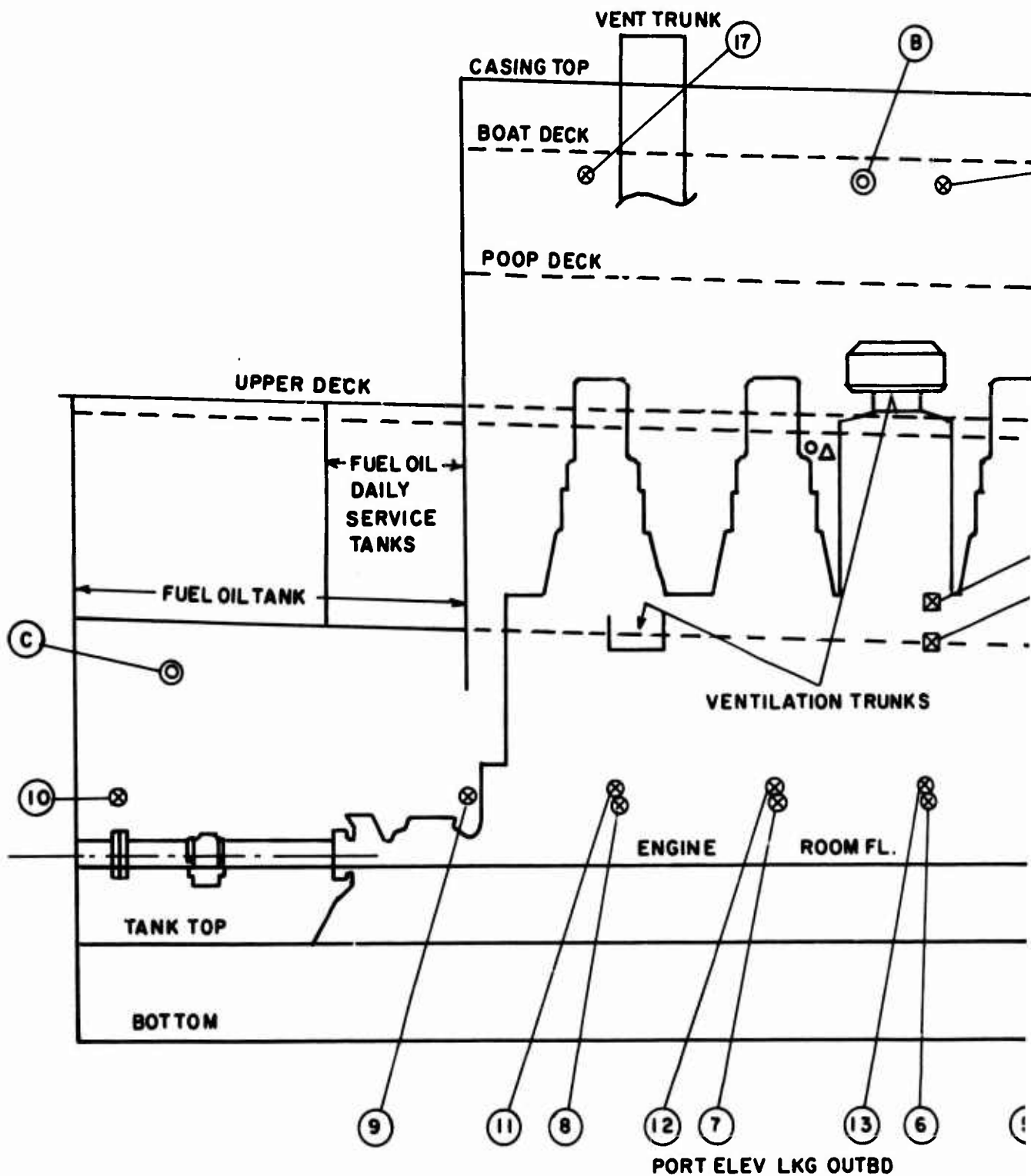
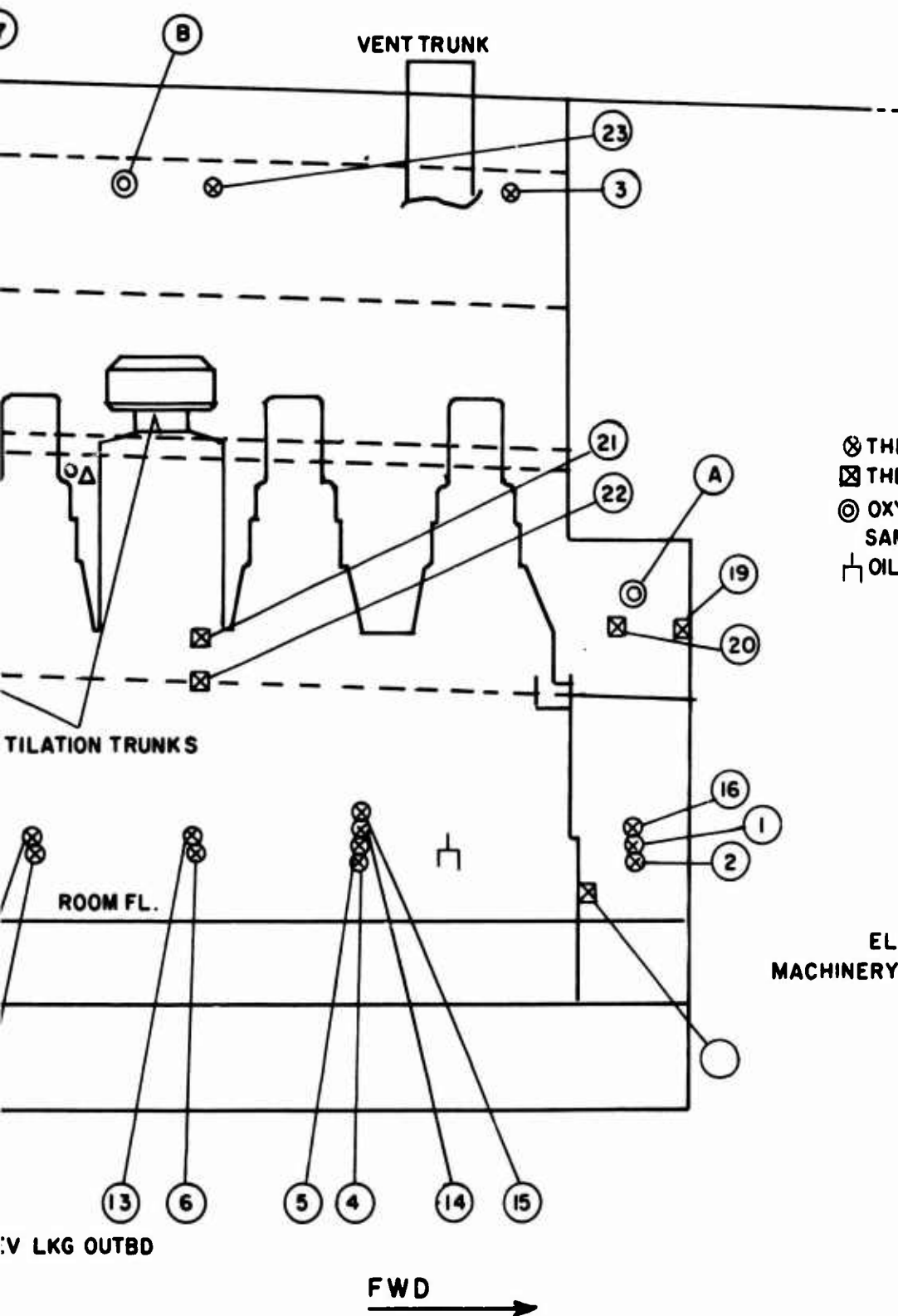


FIGURE 4. MACHINERY SPACE, SECTIONAL VIEW



**ELEVATION VIEW
MACHINERY SPACE M/V RHODE ISLAND**

FACE, SECTIONAL VIEW

VENTILATION DUCT ARRANGEMENT - TOP VIEW

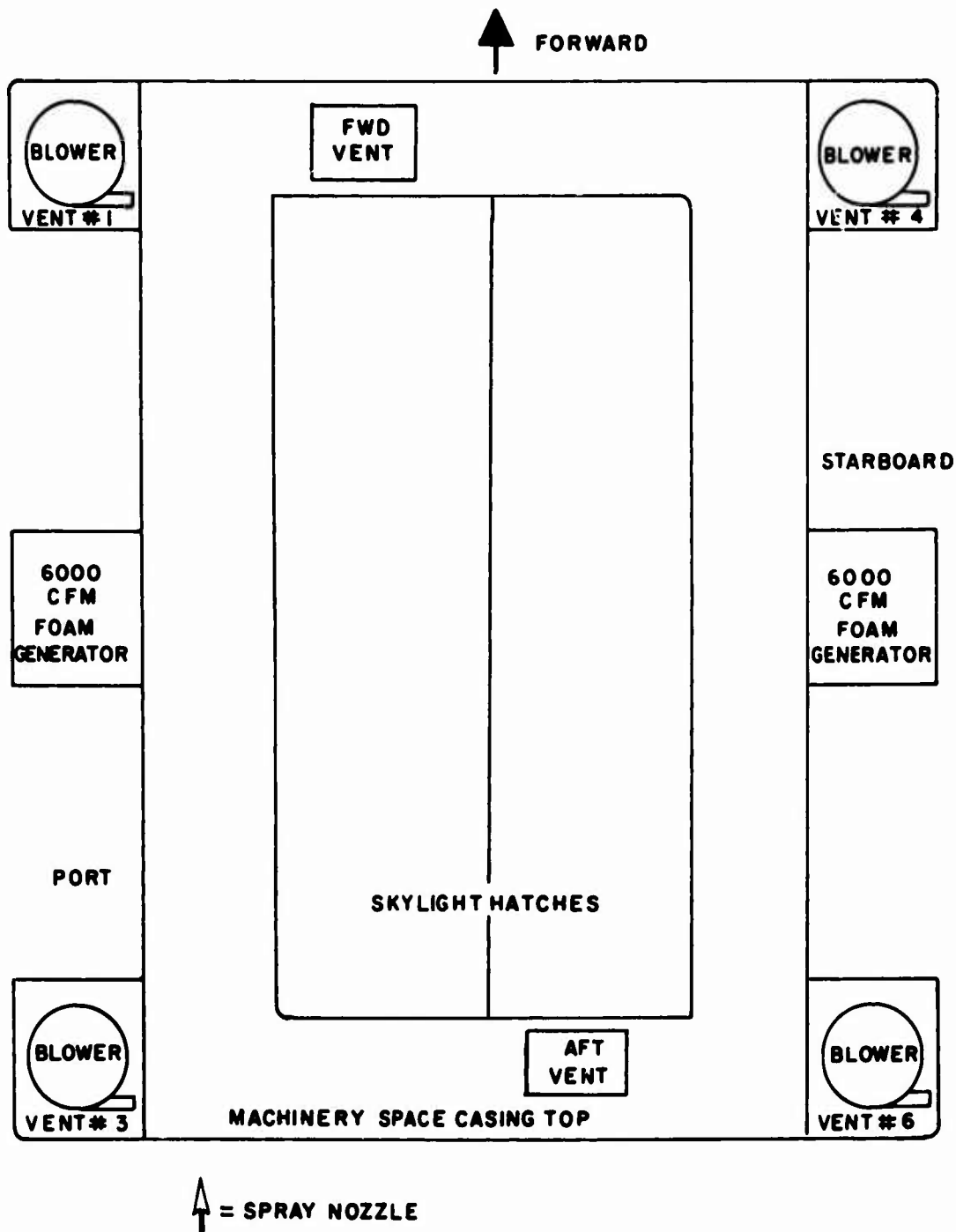


FIGURE 5. VENTILATION DUCT ARRANGEMENT, TOP VIEW

TABLE 1. THERMOCOUPLE LOCATIONS

Thermo-Couple No.	Side of Ship	Distance From C_L	Frame No.	Height Above Deck	Air or Metal	Location
1	C_L	0	42	8'	Air	Vent Duct Port Side Engine
2	Stbd	8'	42	8'	Air	
3	Port	8'		4'	Air	
4	Stbd	8'	36	8'	Metal	
5	Stbd	16'	36	8'	Air	
6	Stbd	5	32	8'	Air	Beam
7	Stbd	8'	28	8'	Metal	
8	Stbd	8'	24	8'	Air	
9	C_L	0	20	8'	Air	Grate
10	C_L	0	10	8'	Air	
11	Port	8'	24	8'	Air	
12	Port	8'	28	8'	Metal	
13	Port	8'	32	8'	Air	
14	Port	8'	36	8'	Air	Column
15	Port	16'	36	8'	Metal	
16	Port	8'	42	8'	Air	
17	Stbd	8'		4'	Air	Vent Duct Stbd Side Engine
18	C_L	0	42	3'	Metal	Fuel Oil Burner
19	C_L	0	44	4'	Metal	Water Tank
20	Port	20	42	20'	Metal	CO ₂ Pipe
21	Stbd	8'	32	20'	Air/Metal	Grate
22	Port	8'	32	15'	Metal	Skylight
23	C_L	0	32	46'	Air	Companionway
24	Port	12	30	30'	Air	

2.3 Fuel

Approximately 5,500 gallons of marine diesel fuel was used for the test series. Marine diesel has a flash point between 130°F and 150°F, and an auto-ignition temperature of approximately 600°F. Water was pumped into the machinery space bilges to provide a base for floating the diesel fuel. At the depth provided by the layering of water and fuel, approximately 1,600 square feet of burnable surface area was available.

To approximate a fire fed by a ruptured fuel line, Test #6 utilized a fuel spray nozzle during preburn and extinguishment. The fuel was discharged through a fuel spray nozzle, located on the port side of the machinery space (see Figures 3 and 4) which directed the fuel downward from a height of ten feet.

2.4 Ignition Method

Primary ignition was aided by the addition of naphtha and paper at two locations, as shown in Figure 3. Three gallons of naphtha was poured on the surface of the marine diesel fuel as a primer at each location. This was ignited with a flare lowered by rope from the upper grating of the machinery space.

2.5 Foam System

Two water-powered high expansion foam generating units delivering a nominal 6,000 cubic feet per minute of 500:1 high expansion foam were utilized for the tests. Each unit weighed 220 lbs and was 40" high, 36" wide and 38" long. They required a water supply of 100 gallons per minute at 100 pounds per square inch gage for optimum performance. Figure 6 shows the performance curves (i.e., volume (cfm) vs. water pressure (psi) vs. expansion ratio) of these units. The manufacturer claims each unit develops sufficient pressure to force the high expansion foam to heights of 50 feet.

Two types of salt water compatible high expansion foam concentrates were used throughout this test series. They are described in Table 2.

The foam generators were installed with a theoretically sufficient diameter opening between the generators and the ducts into which they fed. The cross-sectional area of the ducts was approximately 30 percent larger than the foam generator outlet. One foam generator installation is shown in Figure 7. One test was conducted with a single unit used as a portable generator and ducted in through the skylight. When the two foam units were operated simultaneously, a rate of foam rise of approximately 2.5 feet per minute was produced in the machinery space. This fill rate was measured during a test in which there was no fire. Visual observation was used to determine the fill rate.

2.6 Tests

A total of nine tests were conducted. They were set up to evaluate the effects of preburn time, venting area, and application rate requirements for high expansion foam. General descriptions of these tests showing nominal

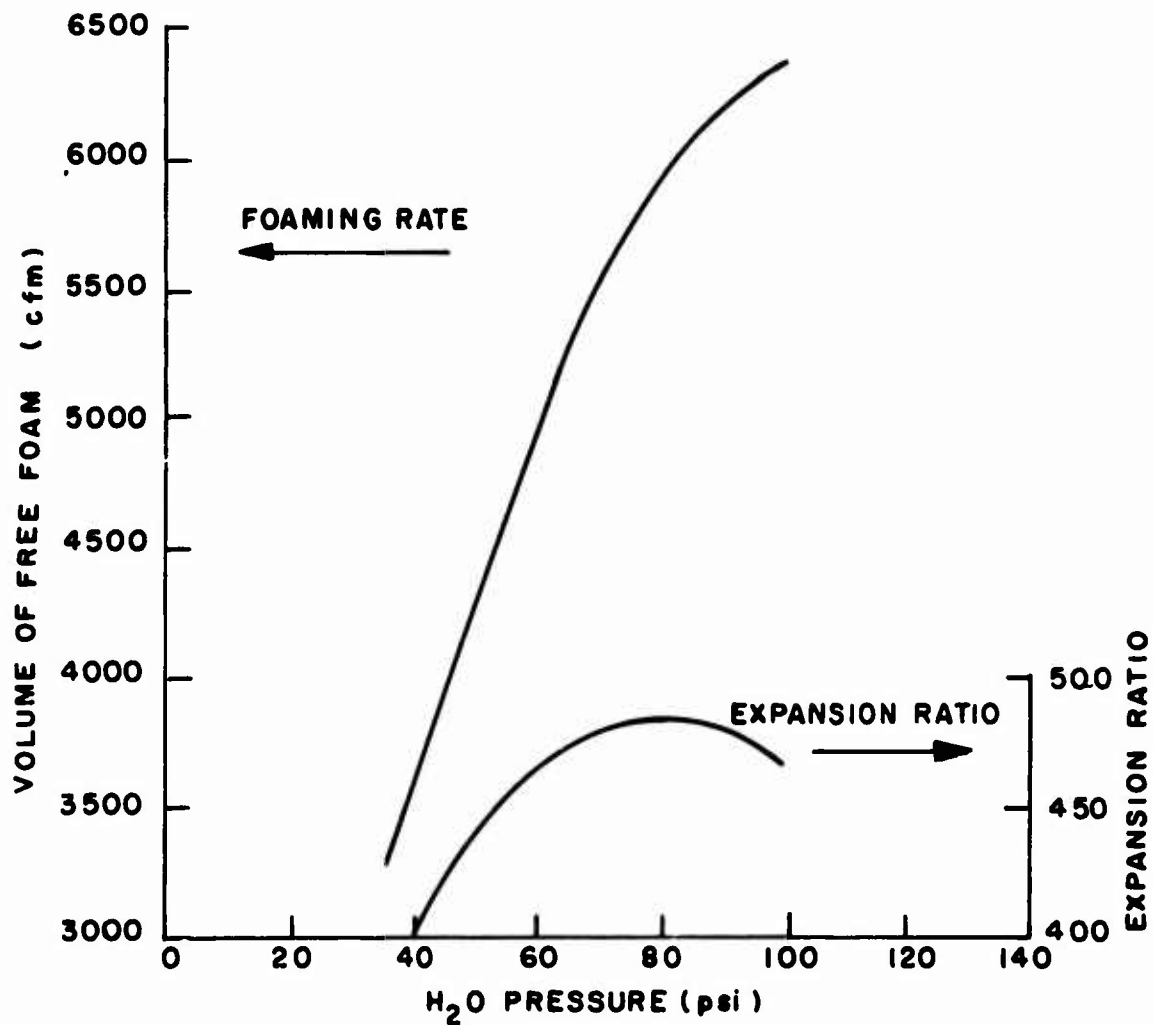


FIGURE 6. PERFORMANCE CURVES FOR
6000 CFM FOAM GENERATOR.

Table 2

Foam Concentrate Characteristics

<u>Characteristic</u>	<u>Regular Foam</u>	<u>Low Temp. Foam</u>
Physical Form	Liquid	Liquid
Type	Synthetic Surfactant	Synthetic Surfactant
Color	Light Yellow	Light Yellow
Viscosity @ 20°C	16.5 cps	14 cps
PH (10% solution)	7.6	9.5
Cloud Point	44°F	15°F
Pour Point	35°F	4°F
Toxicity	By ingestion can cause detergent burn)	By ingestion (can cause detergent burn) has ammonia odor.
Specific Gravity @ 22.5°C	0.98 gm/cc	0.99 gm/cc
Density	8.2 lbs/gal	8.3 lbs/gal
Stability	No changes up to 150°F stored in sealed container.	
Drainage @ 75°F	10% water loss in 5 mins. 50% water loss in 20 mins.	10% water loss in 4 mins. 50% water loss in 15 mins.
Corrosivity	Agent can be stored in stainless steel, rubber or plastic container. Aluminum and steel are attacked and small amounts of corrosion products will impair foam agent performance.	

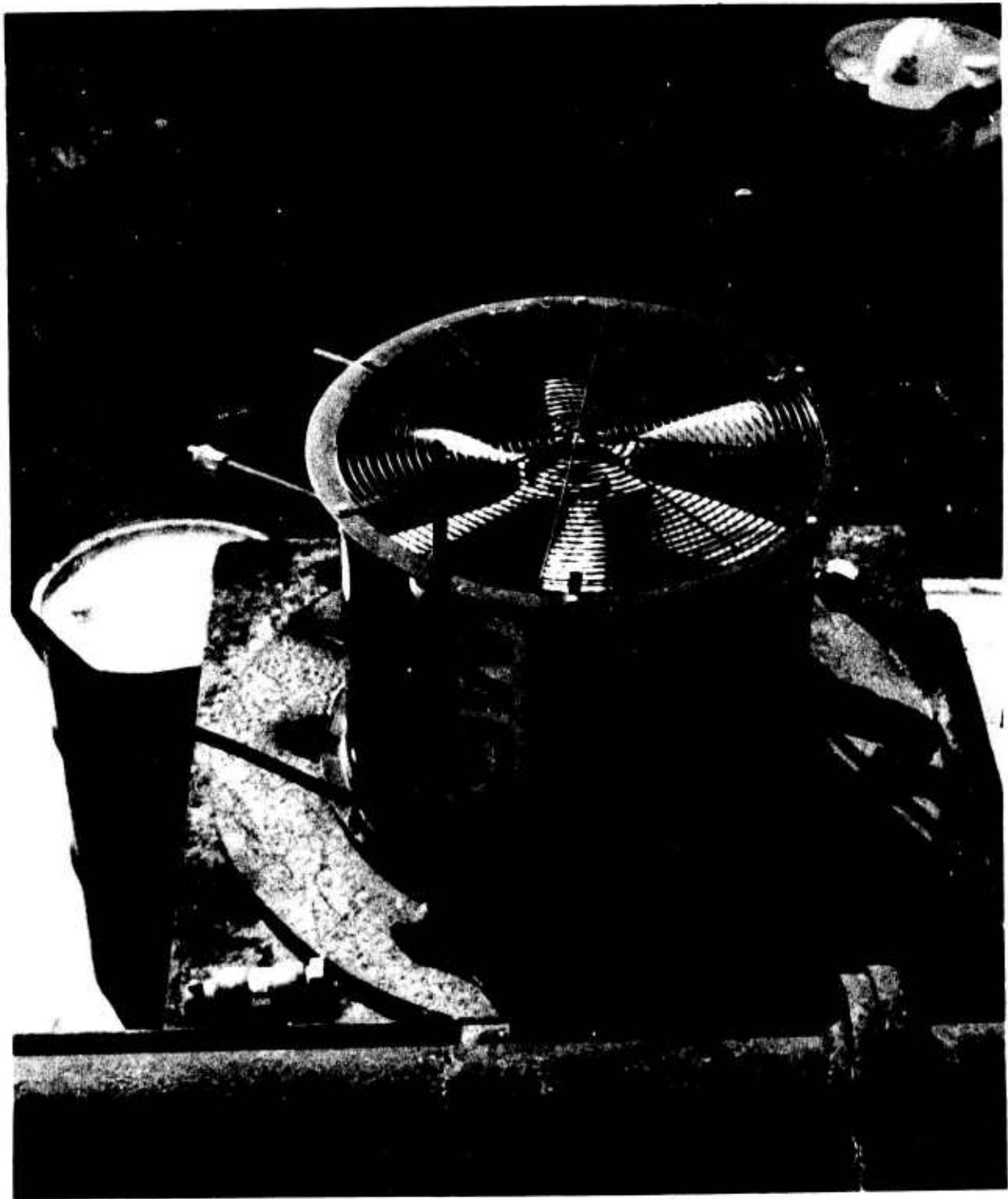


Figure 7. Typical foam generator installation.

values for the primary test variables are listed in Table 3. Figure 8 shows the external effects of preburn. A fuel spray was used during Test #6. It was activated during the latter part of preburn and throughout extinguishment. The spray produces a more severe fire because of the atomization of the fuel. A portable high expansion foam generator was used in Test #7 to evaluate the feasibility of such a last resort system. Test #8 was a carbon dioxide extinguishment test conducted to provide a comparison. Test #9 was used to determine the actual machinery space fill rate with no fire involved as depicted in Figure 9.

3.0 TEST RESULTS

Results of each test are incorporated into summary sheets 3.1 to 3.9 and Figures 10 through 29. The major events were assigned identifying letters and are marked on all of the graphs for reference. Extinguishment time is simply taken as the time during which the foam generators were operational. Since one could not see the fire it was necessary to make an educated guess as to when it was out. This was done by observing the color and quantity of smoke emanating from the machinery space and the point at which the temperatures at key thermocouples began to level off and drop. The result of this technique undoubtedly meant that foam was applied for longer than absolutely necessary. There is no means, however, of estimating this extra time which is reflected in the assumed extinguishment time. The application rate of the high expansion foam was determined by reading the volume of free foam for the known water pressure from Figure 6 and dividing it by the area (1600 square feet) of the machinery space fire. This figure was then multiplied by the number of foam generators employed in the test. The expansion ratio was read directly from Figure 6 for a given water pressure.

Each test summary sheet includes an area of involvement diagram. These diagrams were made by examining the temperatures experienced by thermocouples throughout the grid. All thermocouples which measured temperatures above 100°C are included in the figures of this report. Several problems were encountered with the gas sampling equipment but the data reported is for those sample locations which were known to be producing accurate data. A summary of the most important test results is presented in Table 3.

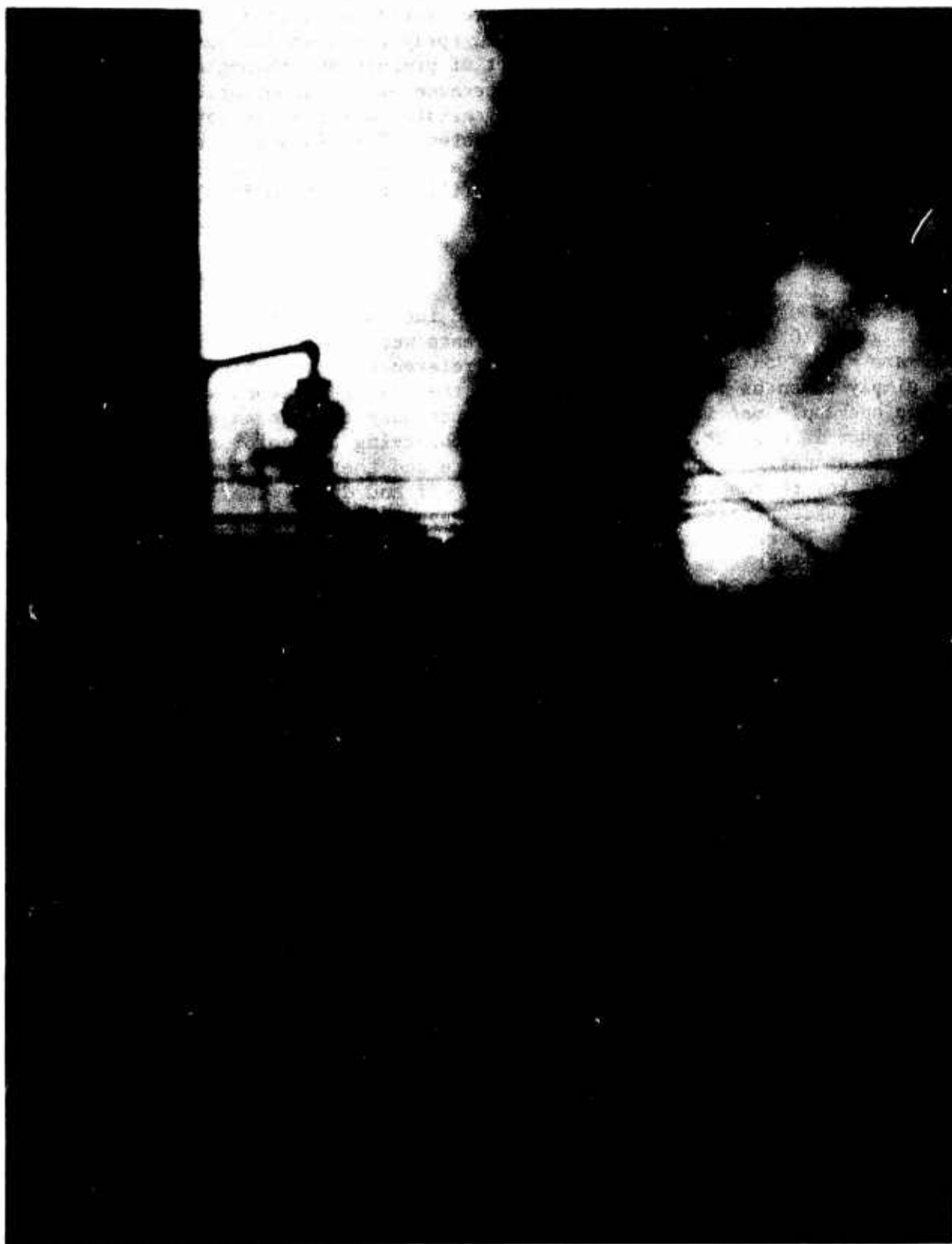


Figure 8. Smoke venting through high expansion foam generator during preburn.

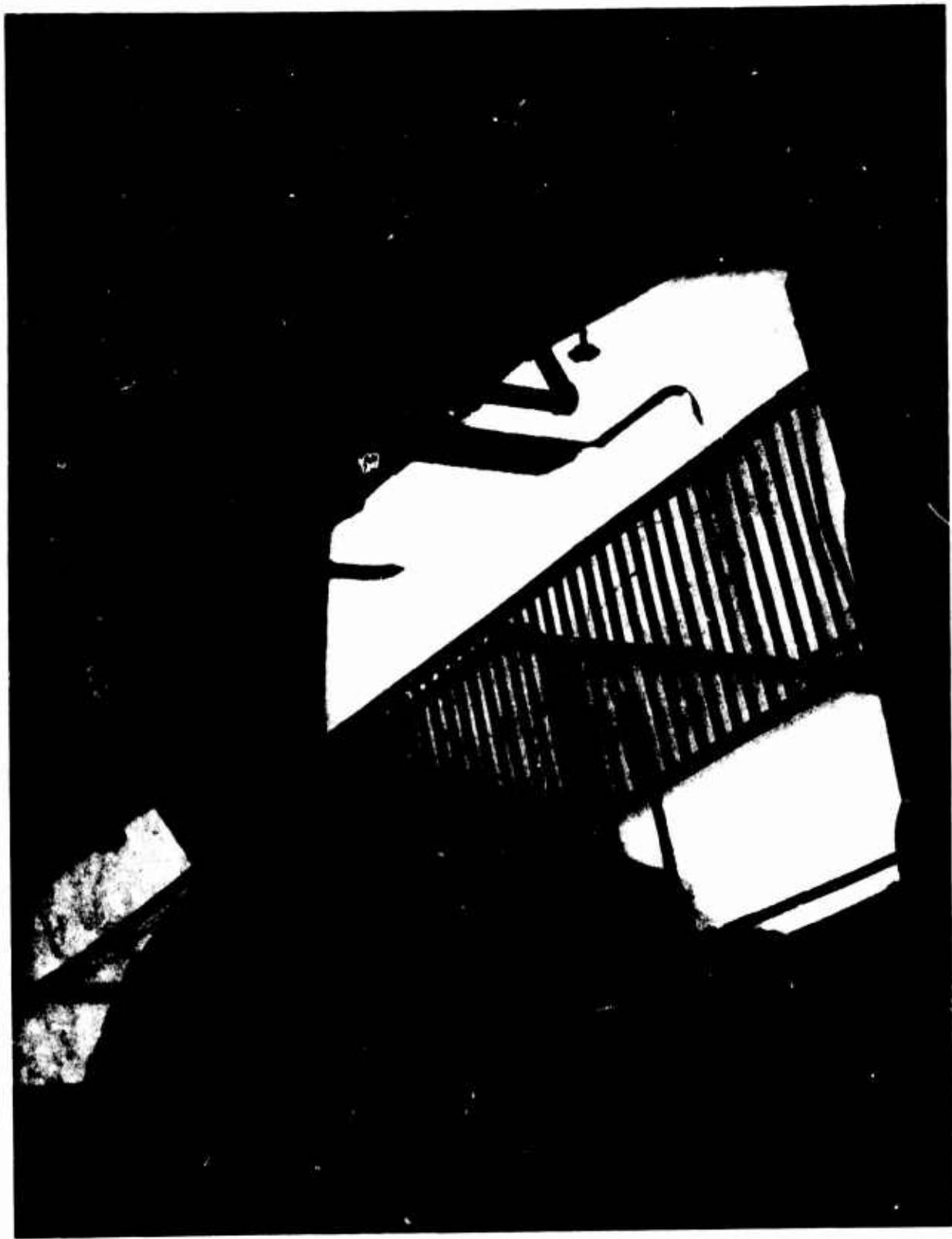


Figure 9. Machinery space partially filled with high expansion foam.

Table 3

Test Data Summary

Test No.	No. Foam Gen.	% Output of Foam Gen.	Type Foam	Pre-Burn Time (min:sec)	Total Exting. Time (min:sec)	Apprx. Appl. Rate (CFM/ft ²)	Expansion Rate	Vent Area ft ²
1	2	100	Reg.	14:49	9:54	7.9	465	--
2	2	100	Reg. & Low Temp.	13:25	4:01	7.9	465	10 fwd 8 aft
3	1	100	Reg.	21:30	4:32	3.9	465	10 fwd 8 aft
4	2	75	Low Temp.	17:13	7:22	5.7	450	19 fwd 17 aft
5	2	50	Reg.	14:10	8:10	4.0	400	19 fwd 17 aft
6*	2	60	Reg.	11:51 *Fuel spray employed	4:18	4.4	465	19 fwd 17 aft
7*	1 *Used portable generator through skylight	100	Reg.	13:25	4:34	3.9	--	19 fwd 9 aft
8	CO ₂ test	2750 lbs	--	11:39	3:00	47 lbs/sec	--	19 fwd 9 aft
9	2	100	Reg.	No fire high expansion foam fill rate test Ave. fill rate 2.5 ft/min.				

3.1 Test #1

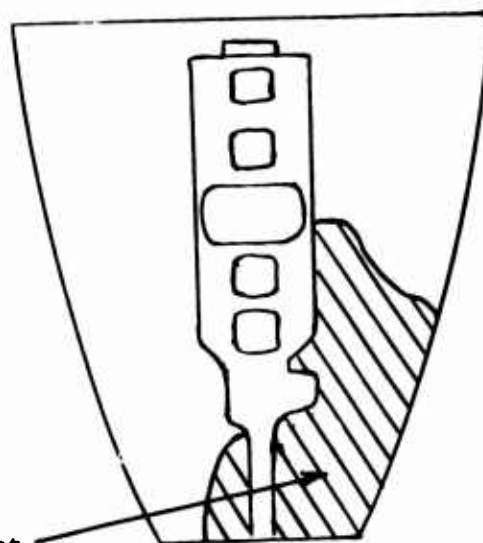
DESCRIPTION: Two generators @ 100%

Test Date: 10 December 1974

Relative Humidity: 30%

Barometric Pressure: 770 mm HG

Area of
Involvement



Machinery
Space

MAJOR EVENTS:

Time

- | | | |
|---|-------|------------------------------------|
| a. Start ventilation blowers | 04:07 | |
| b. Blower shutdown | 14:16 | |
| c. Start foam generators
(end preburn) | 14:49 | Total extinguishment
time: 9:54 |
| d. Generator shutdown
(extinguishment) | 24:43 | |

FOAM APPLIED:

Port gen, 10 gal. low temp, 5 gal reg. \pm 1 gal.

Stbd gen, 20 gal. low temp \pm 1 gal.

Water pressure, 100 \pm 10 psig, Foam expansion ratio, 465 \pm 10

Application rate (average), $\begin{matrix} + 0.1 \\ 7.9 - 0.2 \end{matrix}$ CFM/sq. ft.

VENTILATION:

Forced, 2 blowers, stbd fwd and port aft

Open area, None

REMARKS: Difficulties encountered at first with operation of port foam generator.

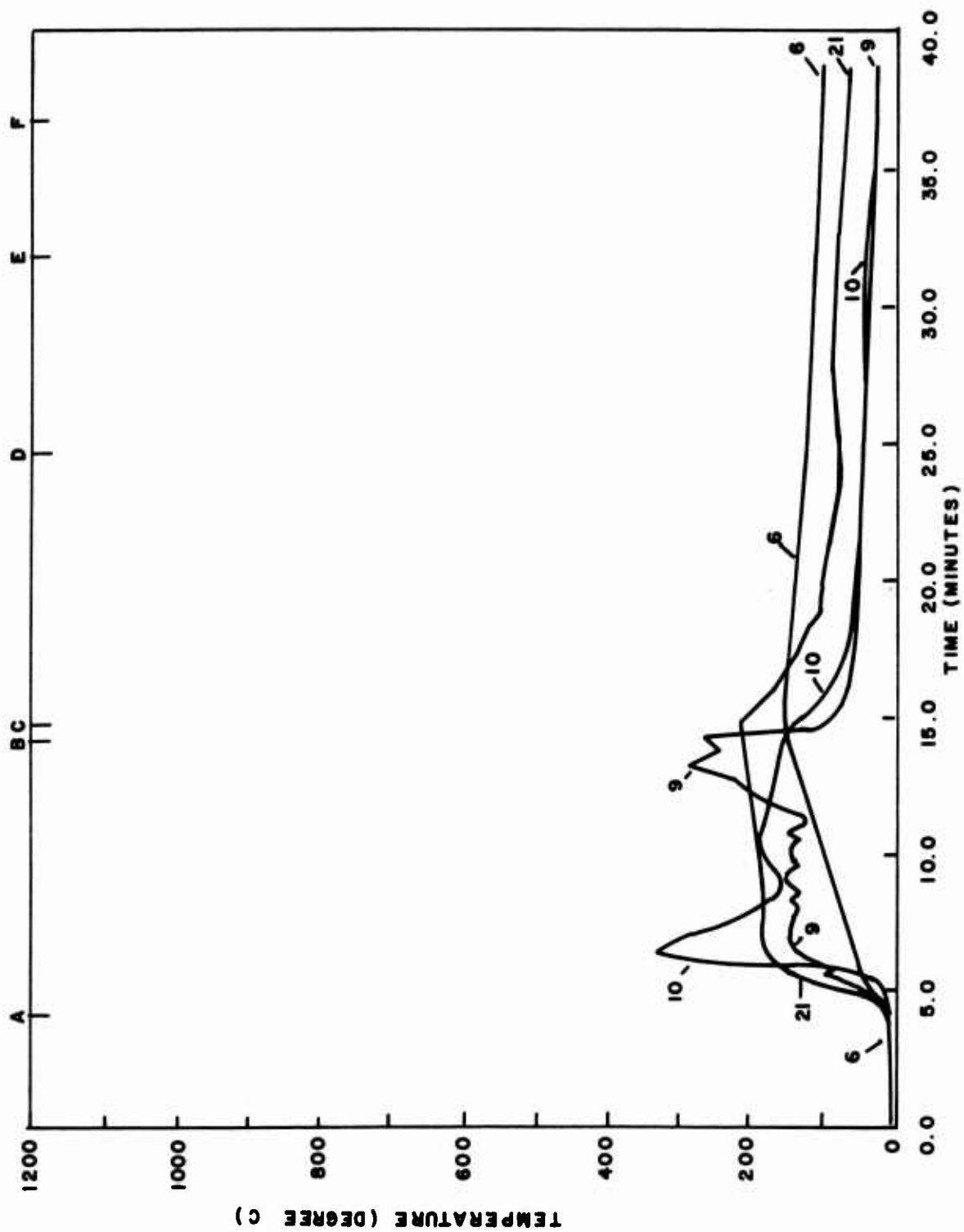


FIGURE 10. TEST 1, TEMPERATURE VS TIME FOR THERMOCOUPLES 6,9,10, & 21.

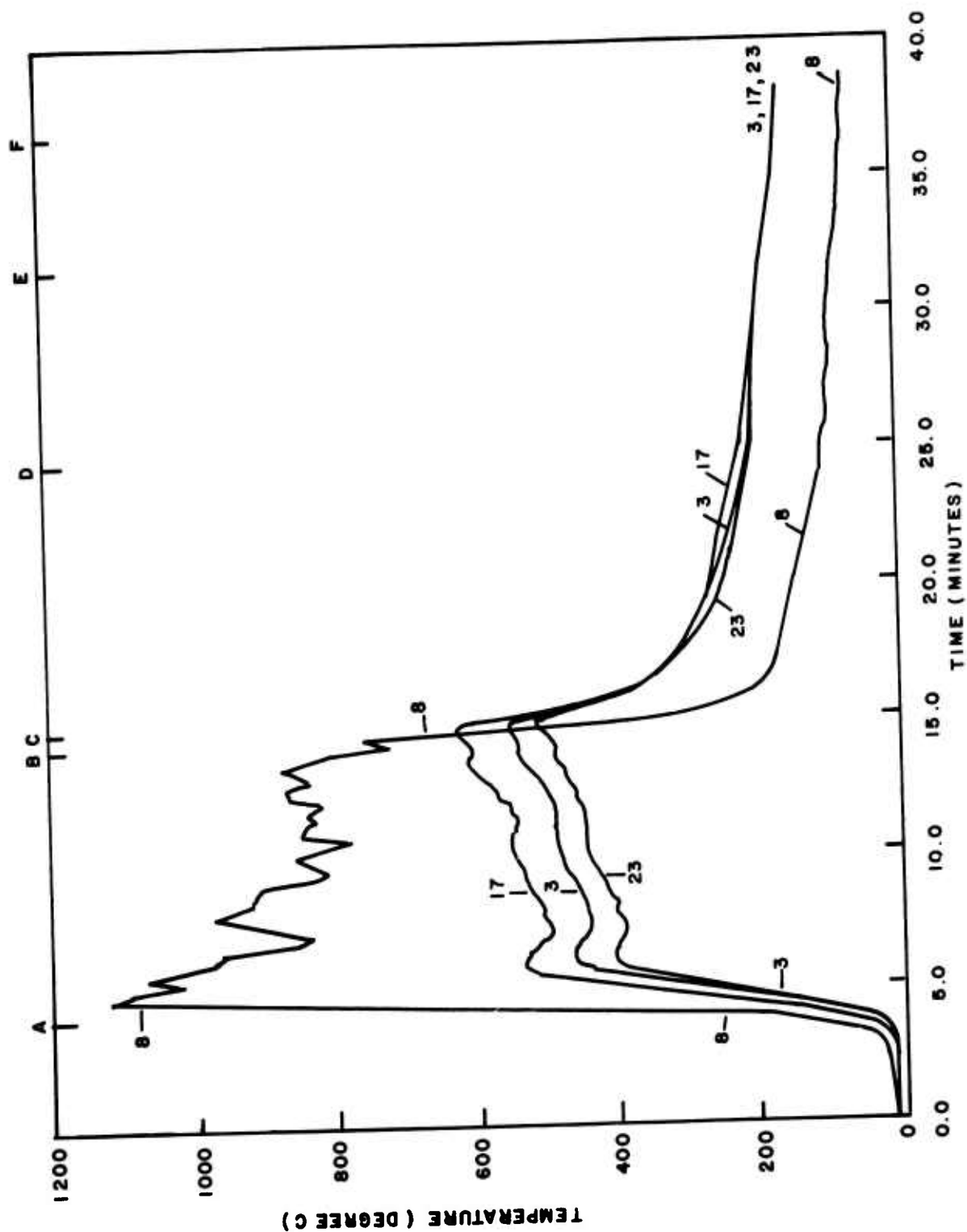


FIGURE 11. TEST 1, TEMPERATURE VS TIME FOR THERMOCOUPLES 3, 8, 17, & 23.

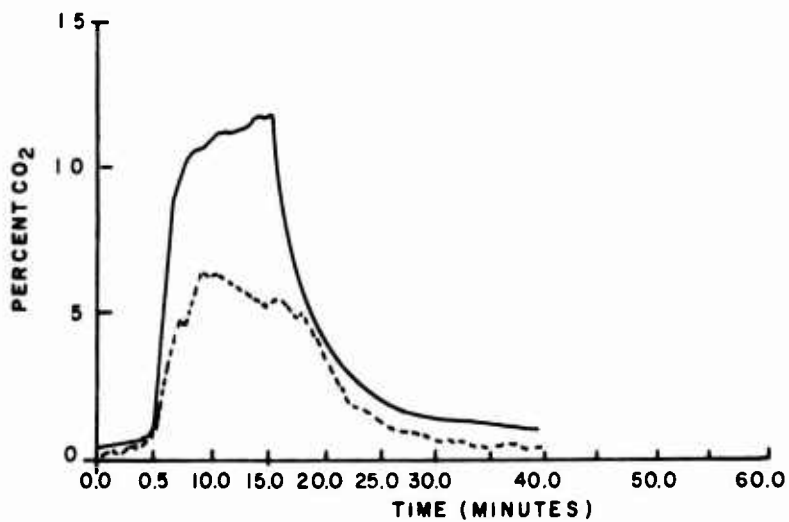
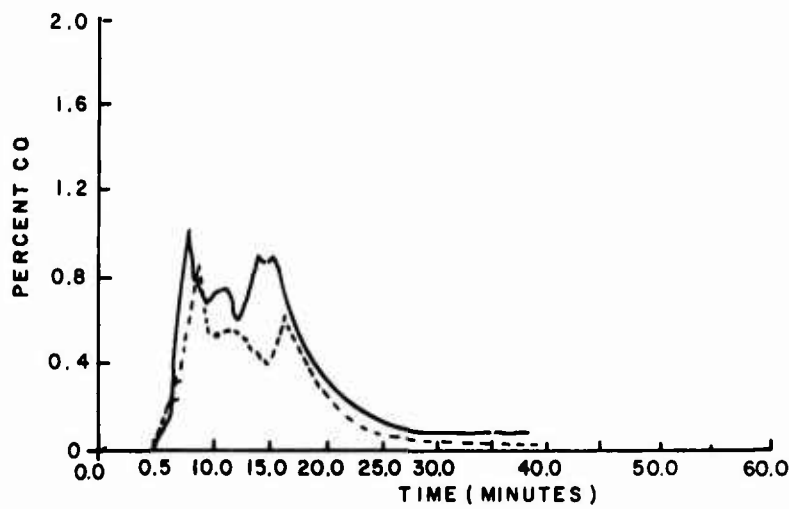
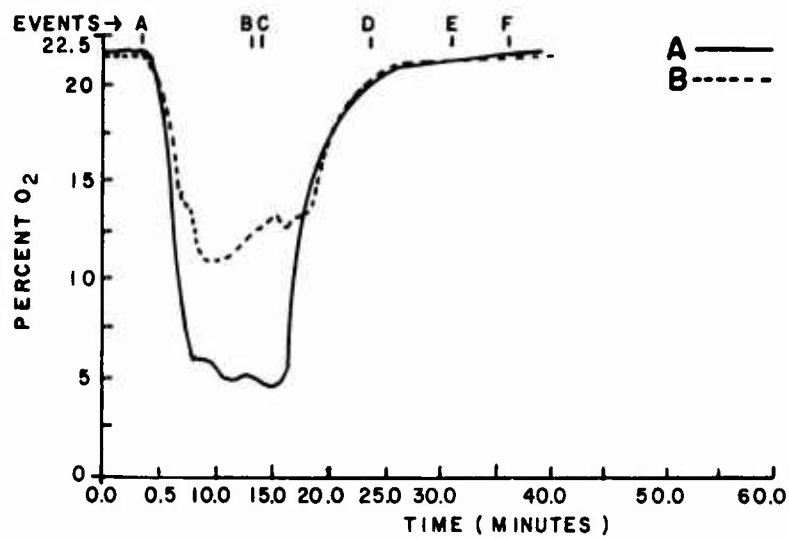


FIGURE 12— GAS ANALYSIS, TEST NO. 1

3.2 Test #2

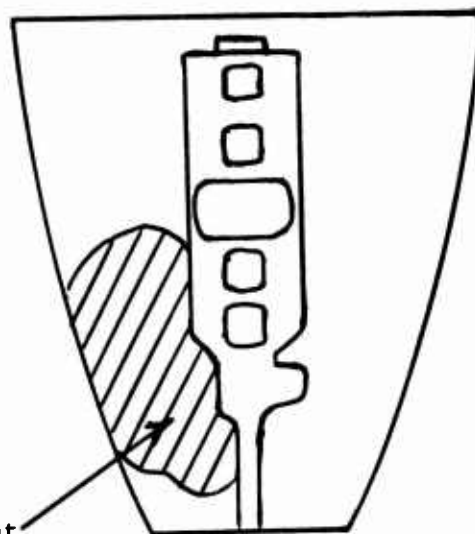
DESCRIPTION: Two generators @ 100%

Test Date: 12 December 1974

Relative Humidity: 75%

Barometric Pressure: 76 mm Hg

Area of
Involvement



Machinery
Space

MAJOR EVENTS:

Time

- | | | |
|---|-------|------------------------------------|
| a. Start ventilation blowers | 03:15 | |
| b. Blower shutdown | 13.25 | |
| c. Start foam generators
(end preburn) | 13:25 | Total extinguishment
time: 4:01 |
| d. Generator shutdown
(extinguishment) | 17:26 | |

FOAM APPLIED:

Port gen, 10 gal. low temp. \pm 1 gal.

Stbd gen, 7 gal. reg. \pm 1/2 gal.

Water pressure, 100 \pm 10 psig. Foam expansion ratio, 465 \pm 10

Application rate (average), 7.9 + 0.1
- 0.2 CFM/sq. ft.

VENTILATION:

Forced, stbd fwd, 1 blower

Open area,

REMARKS: Reflash/hull noticeably hot port side aft.

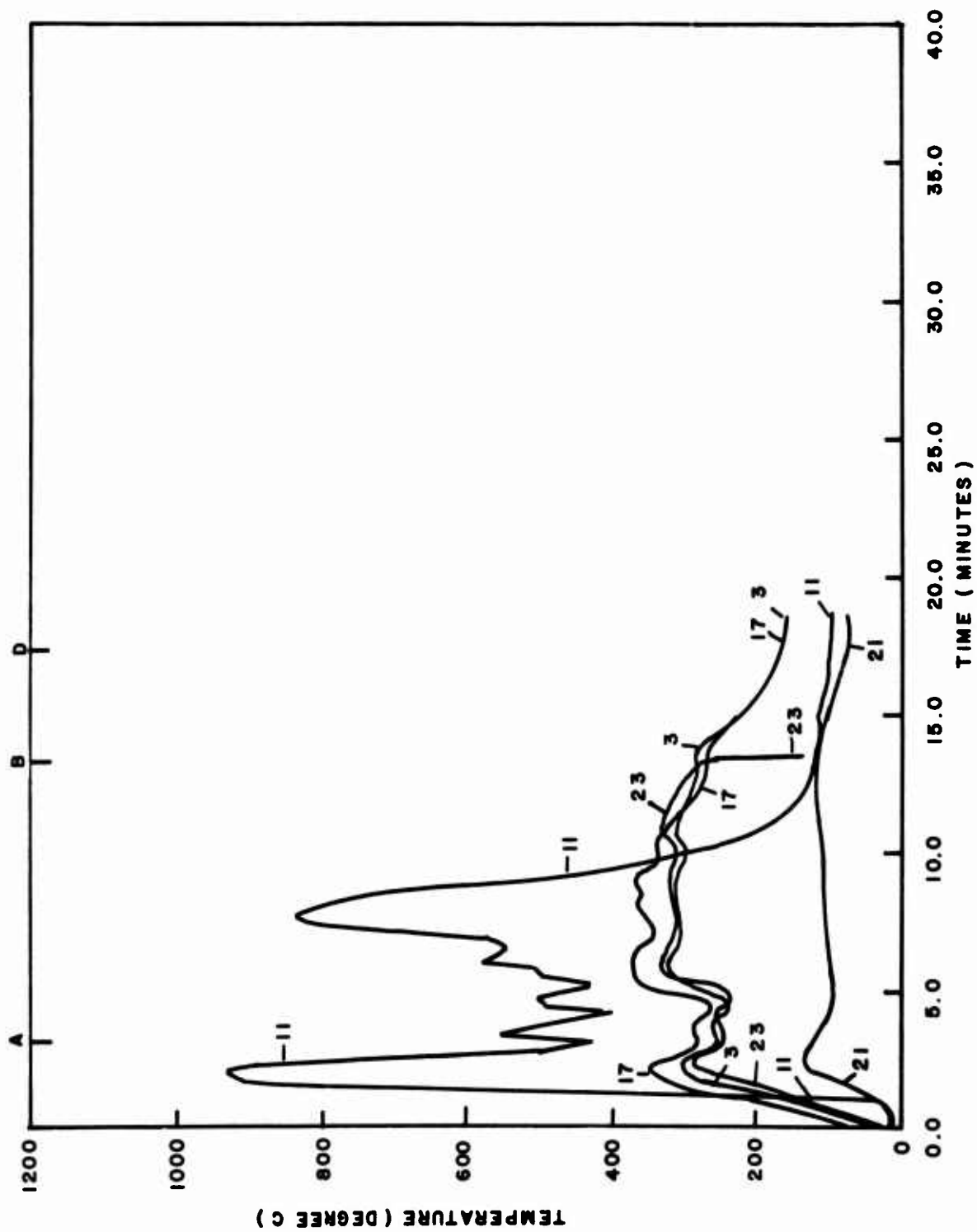


FIGURE 13. TEST 2, TEMPERATURE VS TIME FOR THERMOCOUPLES 3, 11, 17, 21, & 23.

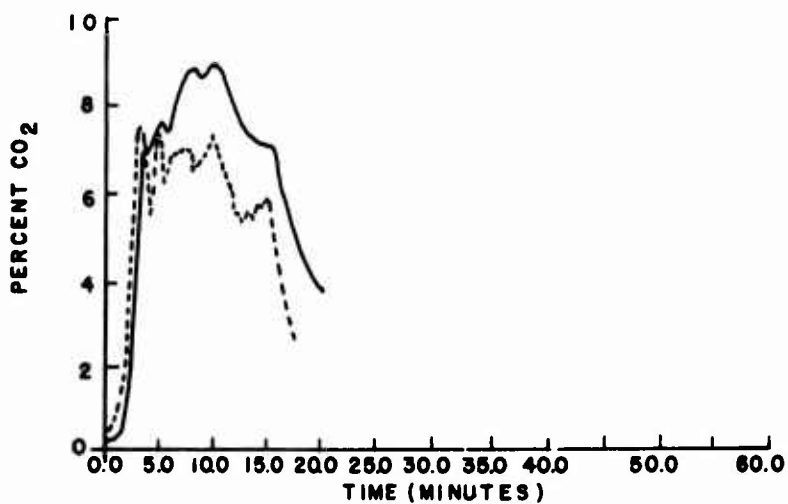
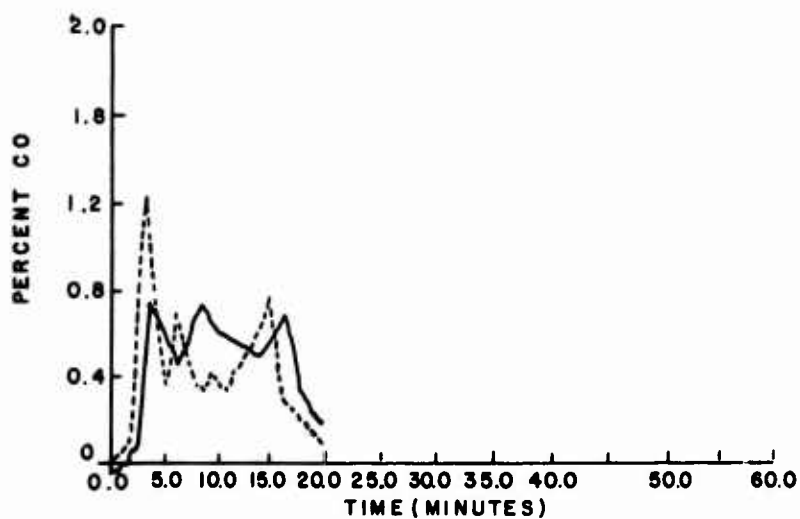
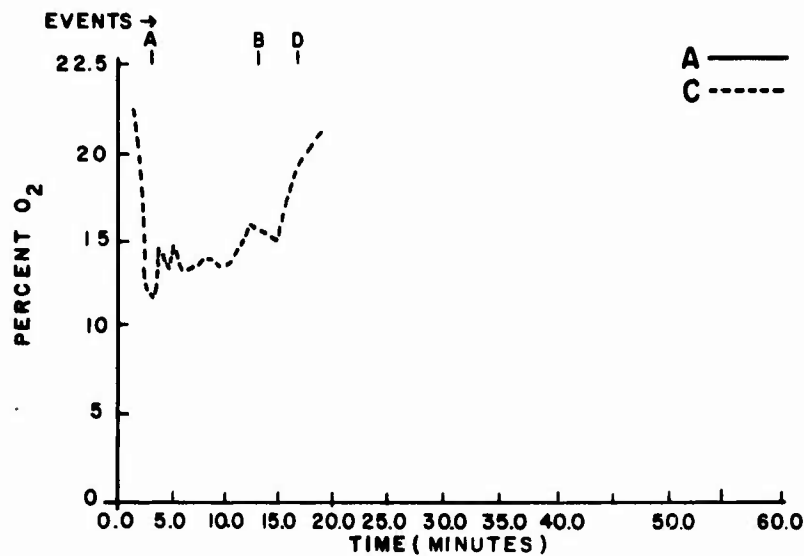


FIGURE 14- GAS ANALYSIS, TEST NO.2

3.3 Test #3

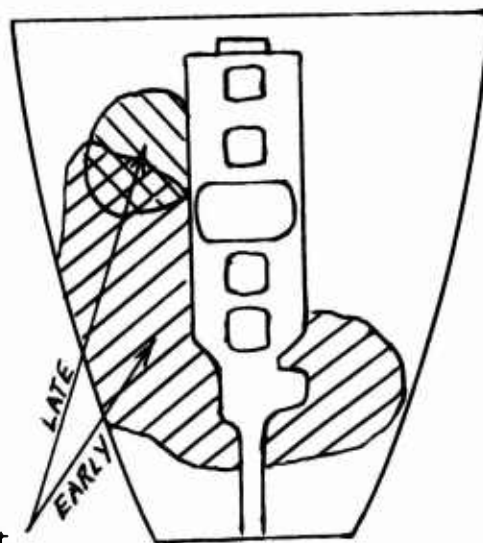
DESCRIPTION: One generator @ 100% port side

Test Date: 13 December 1974

Relative Humidity: 83%

Barometric Pressure: 770 mm Hg

Area of
Involvement



Machinery
Space

MAJOR EVENTS:

Time

- | | | |
|---|----------------------|----------------------|
| a. Start ventilation blowers | 01:21/again at 15:20 | |
| b. Blower shutdown | 09:16/again at 19:30 | |
| c. Start foam generators
(end preburn) | 21:30 | Total extinguishment |
| d. Generator shutdown
(extinguishment) | 26:02 | time: 4:32 |

FOAM APPLIED:

Port gen, 10 gal. reg. \pm 1 gal.

Stbd gen, --

Water pressure, 100 \pm 10 psig. Foam expansion ratio, 465 \pm 10

Application rate (average), 3.9 \pm 0.05 CFM/sq. ft.
- 0.1

VENTILATION:

Forced, 1 blower, port fwd (37,500 CFM)

Open area, Fwd vent (10 ft²) and aft vent (8 ft²)

REMARKS: Foam may have pushed fire fwd.

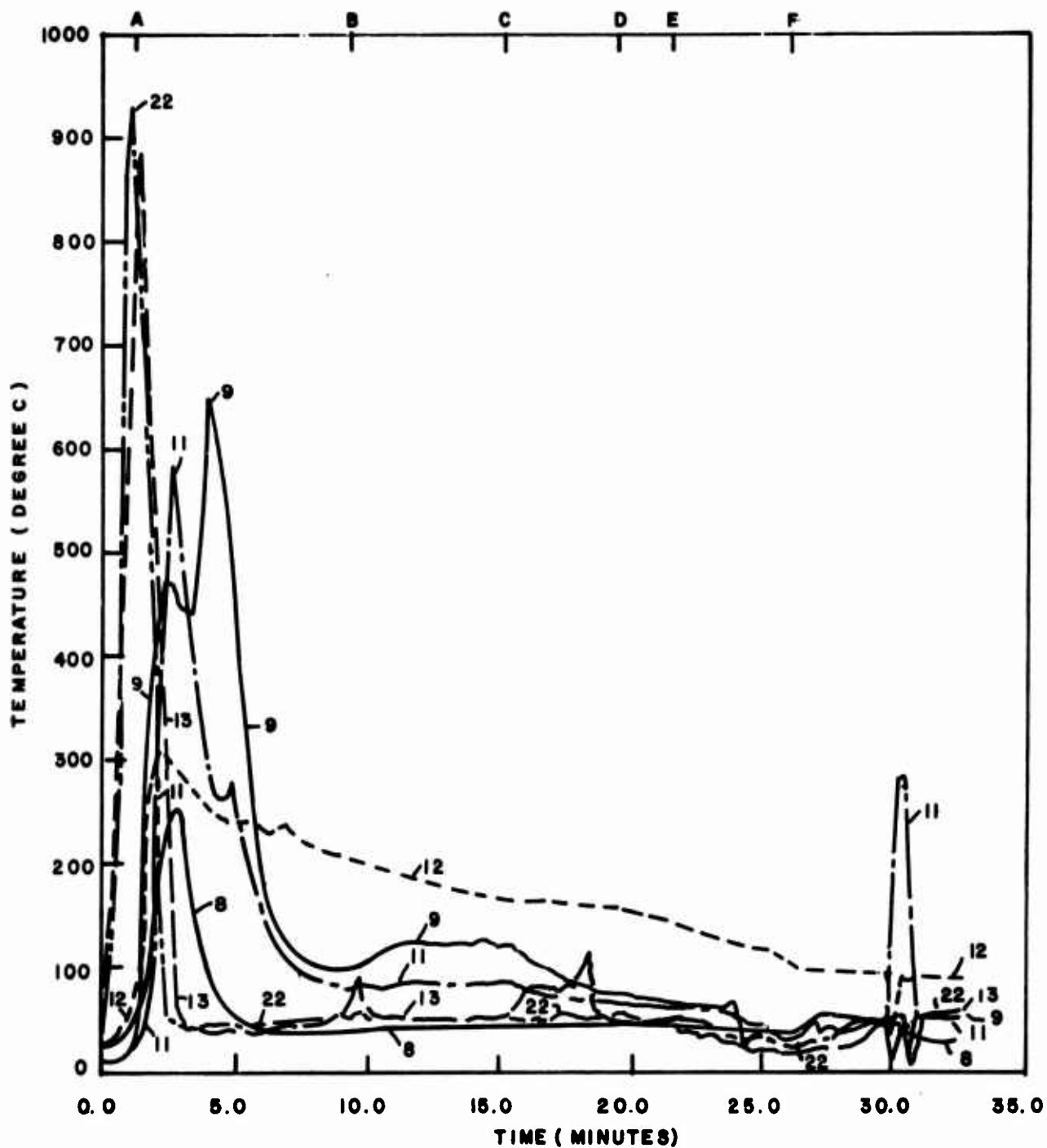


FIGURE 15. TEST 3, TEMPERATURE VS TIME FOR THERMOCOUPLES 8, 9, 11, 12, 13, & 22.

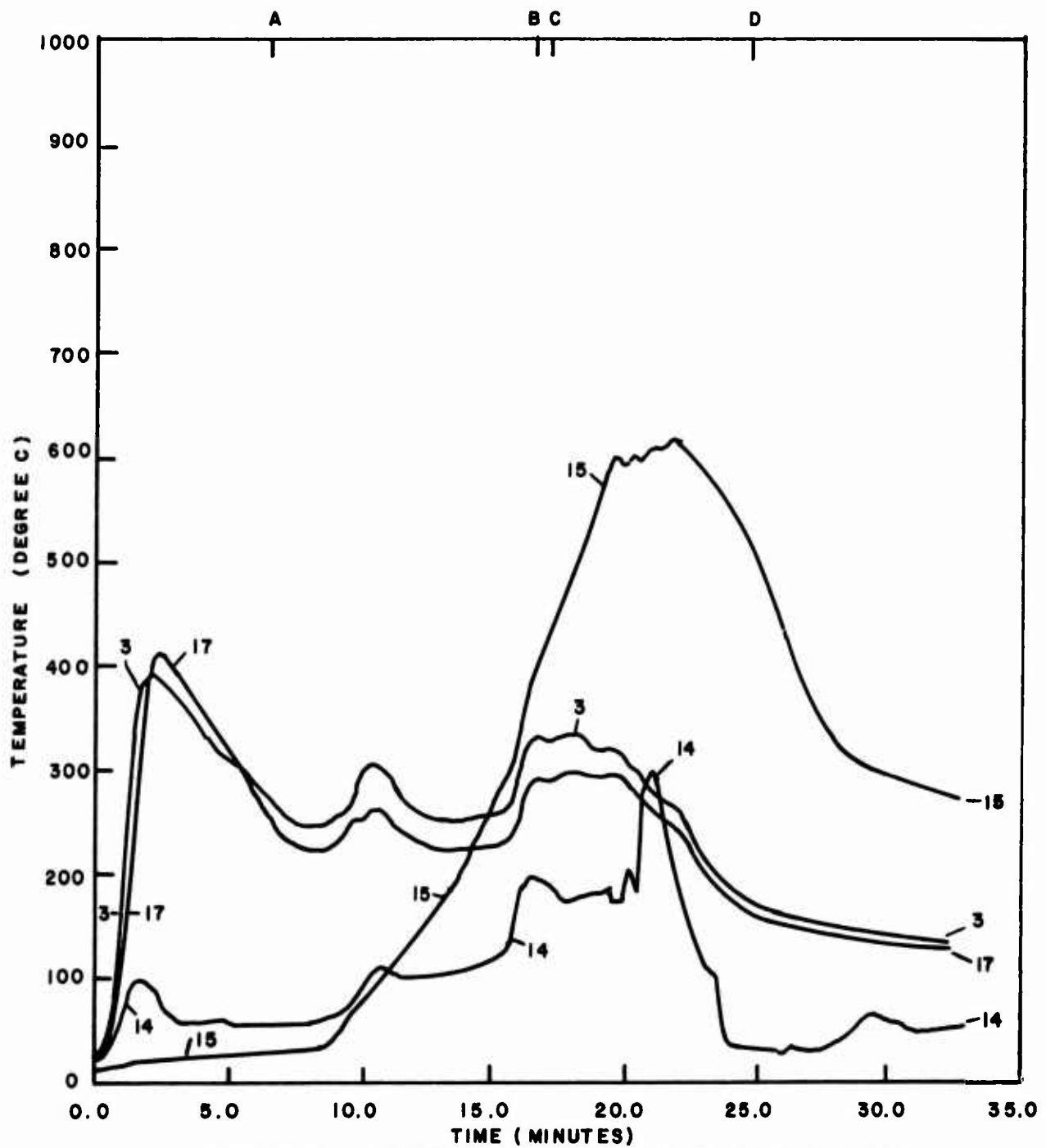


FIGURE 16 - TEST 3, TEMPERATURE VSTIME FOR
THERMOCOUPLES 3, 14, 15, & 17

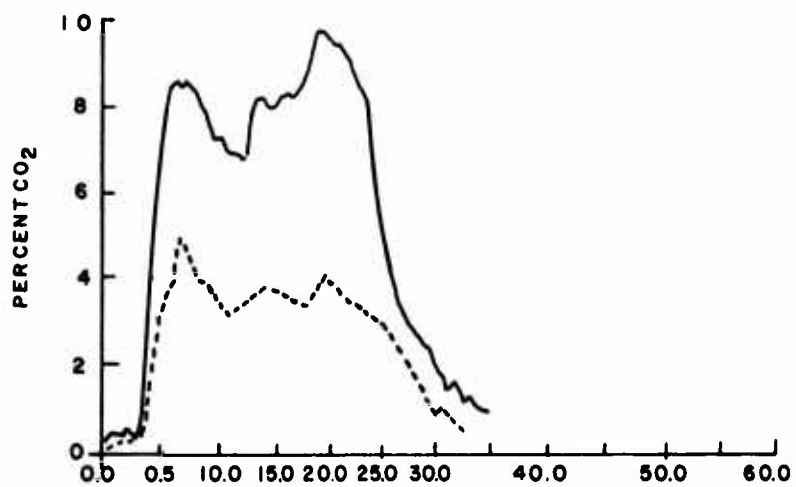
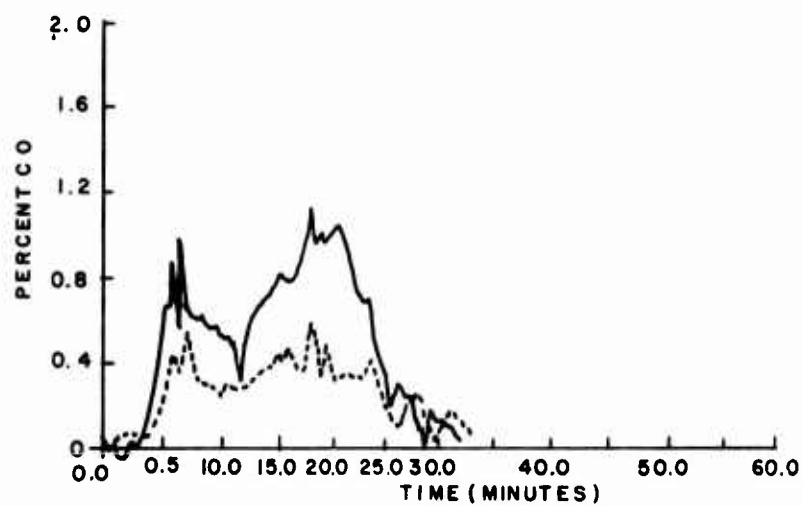
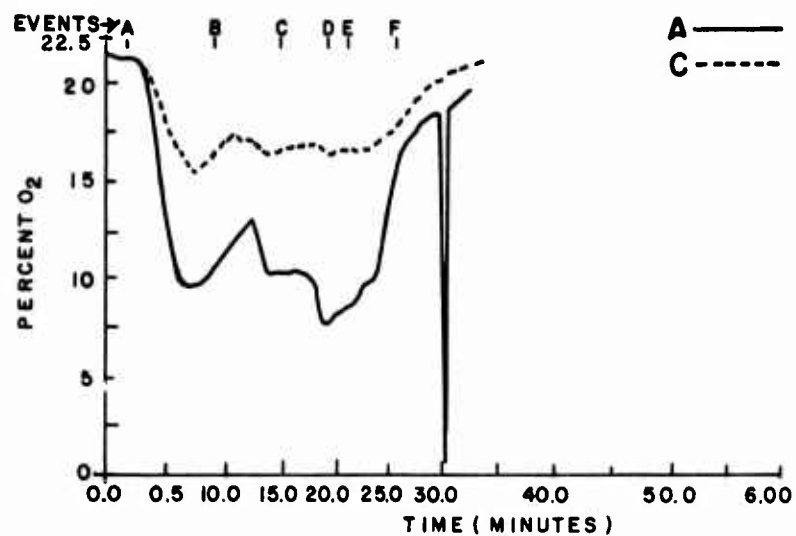


FIGURE 17—GAS ANALYSIS, TEST NO. 3

3.4 Test #4

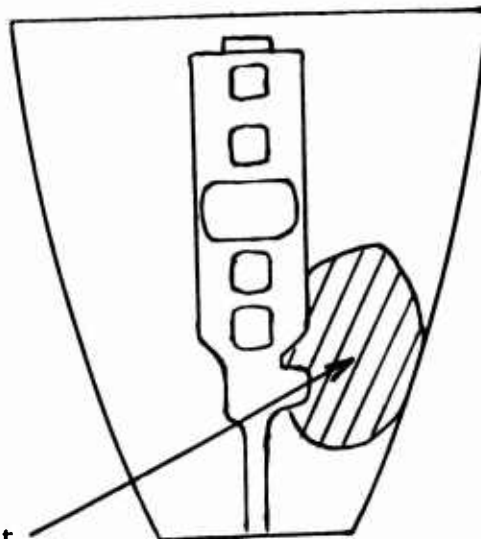
DESCRIPTION: Two generators @ 75%

Test Date: 16 December 1974

Relative Humidity: 55%

Barometric Pressure: 762 mm Hg

Area of
Involvement



Machinery
Space

MAJOR EVENTS:

Time

- | | | |
|---|-------|----------------------|
| a. Start ventilation blowers | 06:34 | |
| b. Blower shutdown | 16:40 | |
| c. Start foam generators
(end preburn) | 17:13 | Total extinguishment |
| d. Generator shutdown
(extinguishment) | 24:35 | time: 7:22 |

FOAM APPLIED:

Port gen, 10 gal. low temp. ± 1 gal.

Stbd gen, 7 gal. low temp. ± 1 gal.

Water pressure, 55 ± 5 psig. Foam expansion ratio, 450 ± 10

Application rate (average), 5.7 ± 0.4 CFM/sq. ft.

VENTILATION:

Forced, N/A

Open area, Fwd vent (10 ft^2), aft vent (8 ft^2) and 2 vent ducts (9 ft^2 each)

REMARKS:

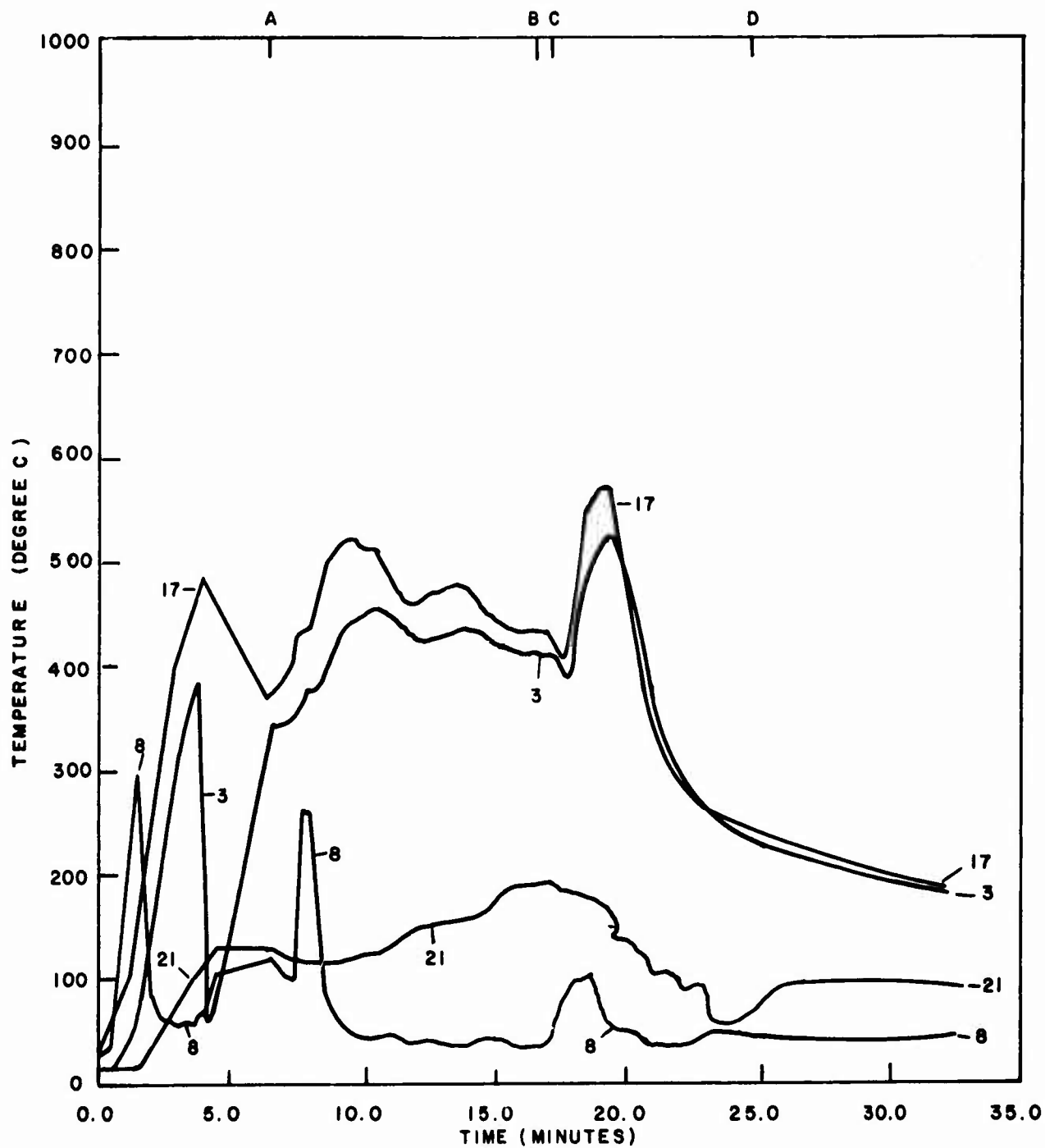


FIGURE 18 - TEST 4, TEMPERATURE VS TIME FOR
THERMOCOUPLES 3, 8, 17, & 21

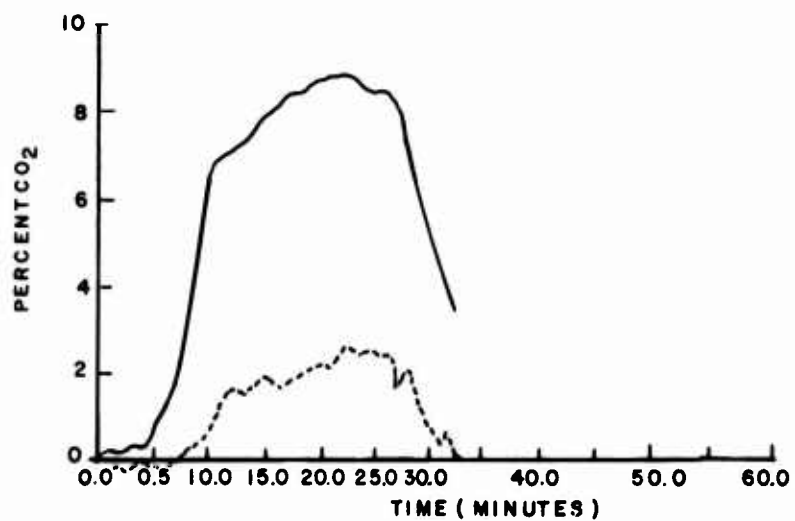
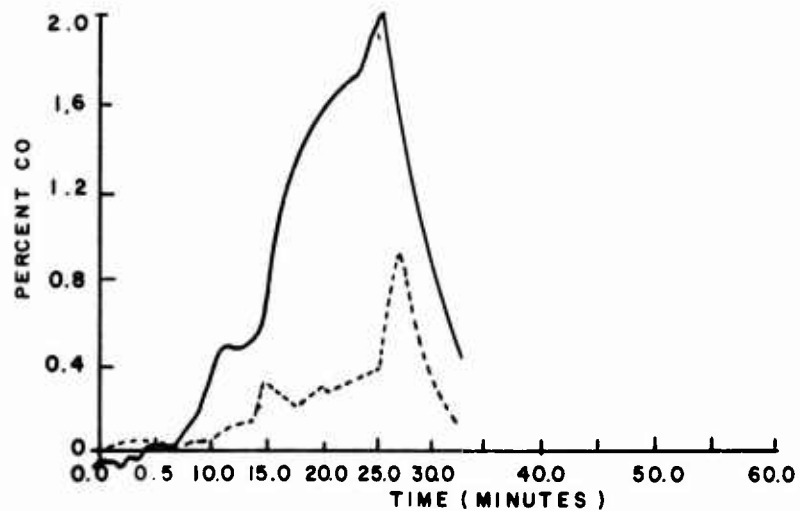
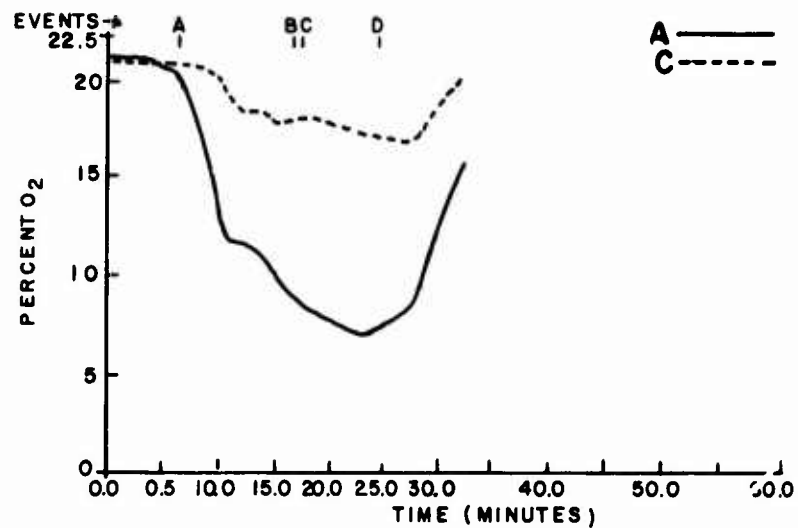


FIGURE 19 - GAS ANALYSIS, TEST NO. 4

3.5 Test #5

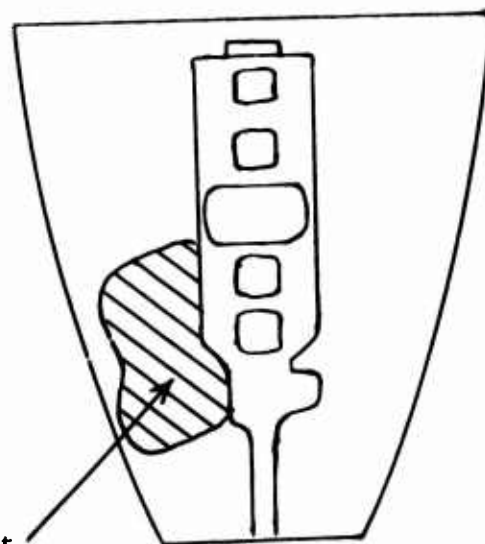
DESCRIPTION: Two generators @ 50%

Test Date: 16 December 1974

Relative Humidity: 32%

Barometric Pressure: 760 mm Hg

Area of
Involvement



Machinery
Space

MAJOR EVENTS:

Time

- | | | |
|---|-------|------------------------------------|
| a. Start ventilation blowers | 03:18 | |
| b. Blower shutdown | 13:43 | |
| c. Start foam generators
(end preburn) | 14:10 | Total extinguishment
time: 8:10 |
| d. Generator shutdown
(extinguishment) | 22:20 | |

FOAM APPLIED:

Port gen, 10 gal. reg. \pm 1 gal.

Stbd gen, 7 gal. reg. \pm 1 gal.

Water pressure, 35 \pm 3 psig. Foam expansion ratio, less than 400

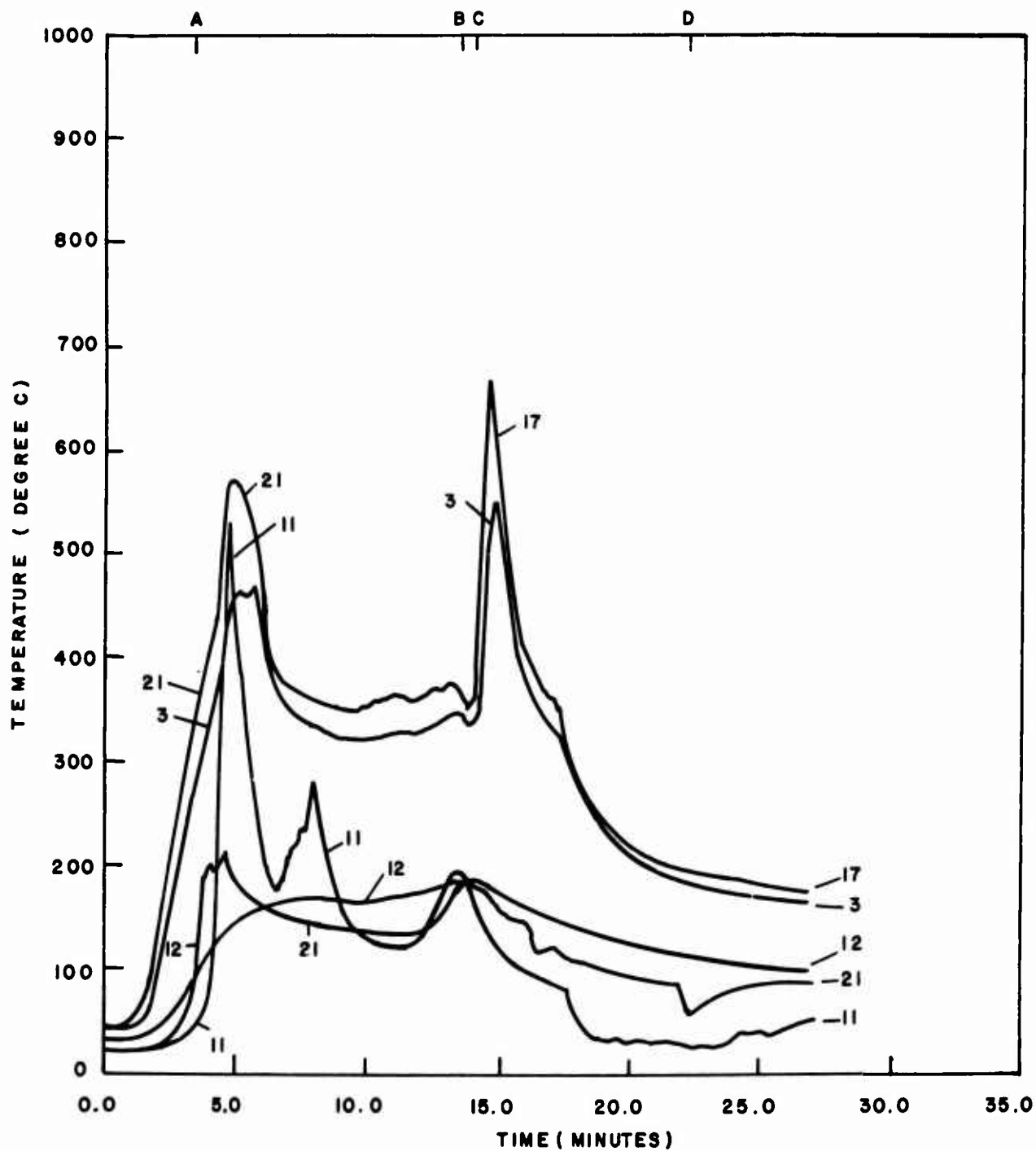
Application rate (average), 4.0 \pm 0.3 CFM/sq. ft.

VENTILATION:

Forced, N/A

Open area, Fwd vent (10 ft²), aft vent (8 ft²), and 2 vent ducts (9 ft² each)

REMARKS:



**FIGURE 20.- TEST 5, TEMPERATURE VS TIME FOR
THERMOCOUPLES 3, 11, 12, 17 & 21**

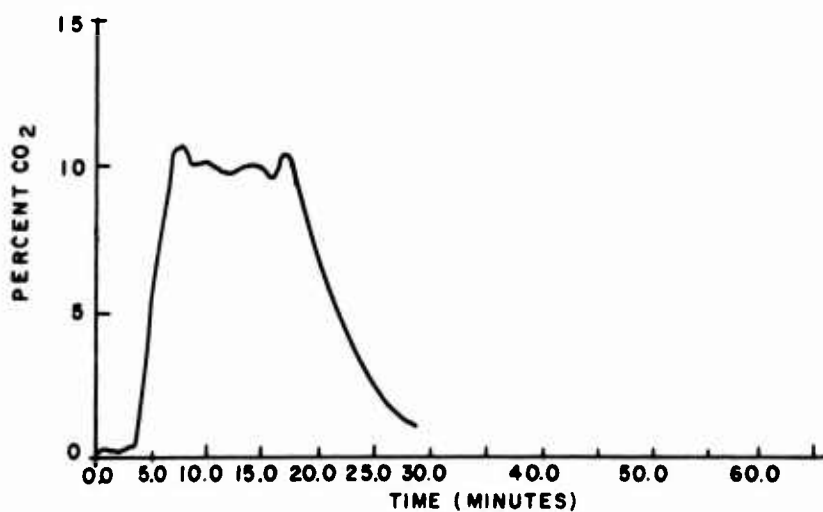
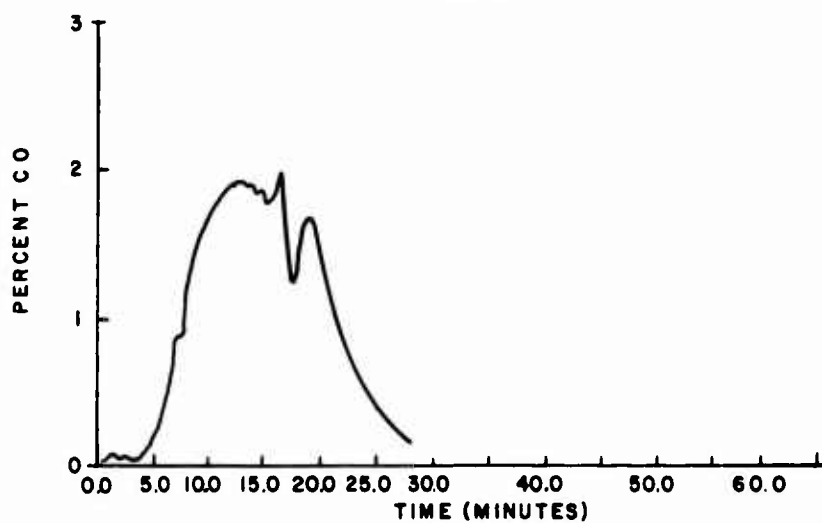
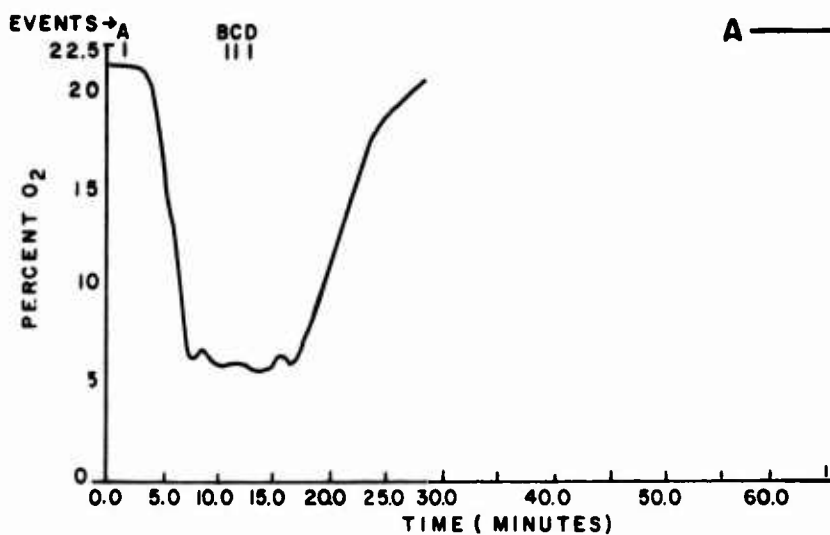


FIGURE 21- GAS ANALYSIS, TEST NO. 5

3.6 Test #6

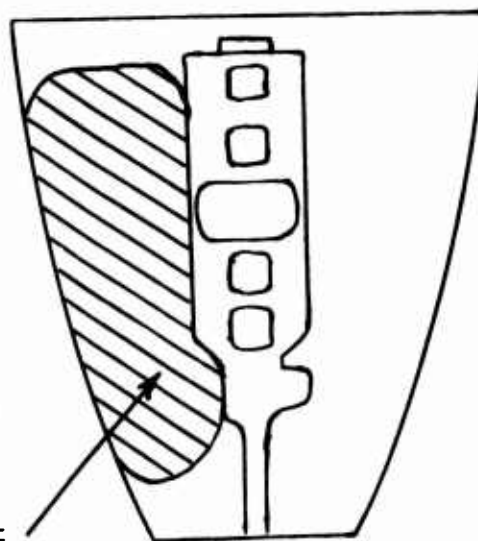
DESCRIPTION: Two generators @ 60% with fuel spray

Test Date: 17 December 1974

Relative Humidity: 53%

Barometric Pressure: 763 mm Hg

Area of
Involvement



Machinery
Space

MAJOR EVENTS:

Time

- | | | |
|---|-------|------------------------------------|
| a. Start ventilation blowers | 01:37 | |
| b. Blower shutdown | 11:19 | |
| c. Start foam generators
(end preburn) | 11:51 | Total extinguishment
time: 4:18 |
| d. Generator shutdown
(extinguishment) | 16:09 | |

FOAM APPLIED:

Port gen, 13 gal. reg. \pm 1 gal.

Stbd gen, 8 gal. reg. \pm 1 gal.

Water pressure, 40 ± 5 psig. Foam expansion ratio, 400 ± 15

Application rate (average), 4.4 ± 0.4 CFM/sq. ft.

VENTILATION:

Forced, N/A

Open area, Fwd vent (10 ft^2), aft vent (8 ft^2), and 2 vent ducts (9 ft^2 each)

REMARKS: Used fuel spray during preburn and extinguishment. It did not seem to have a significant effect.

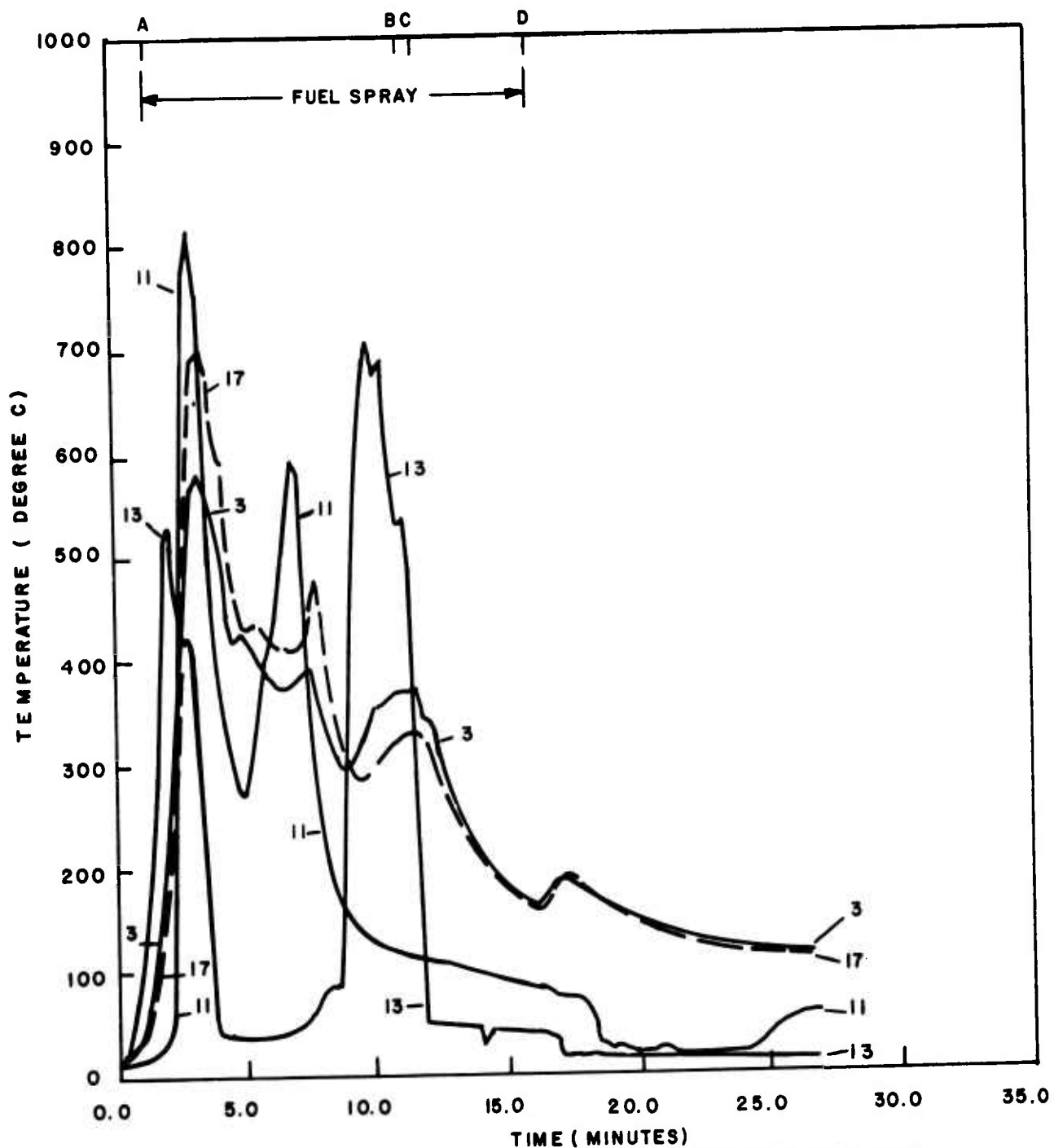


FIGURE 22- TEST 6, TEMPERATURE VSTIME FOR THERMOCOUPLES 3, 11, 13, & 17.

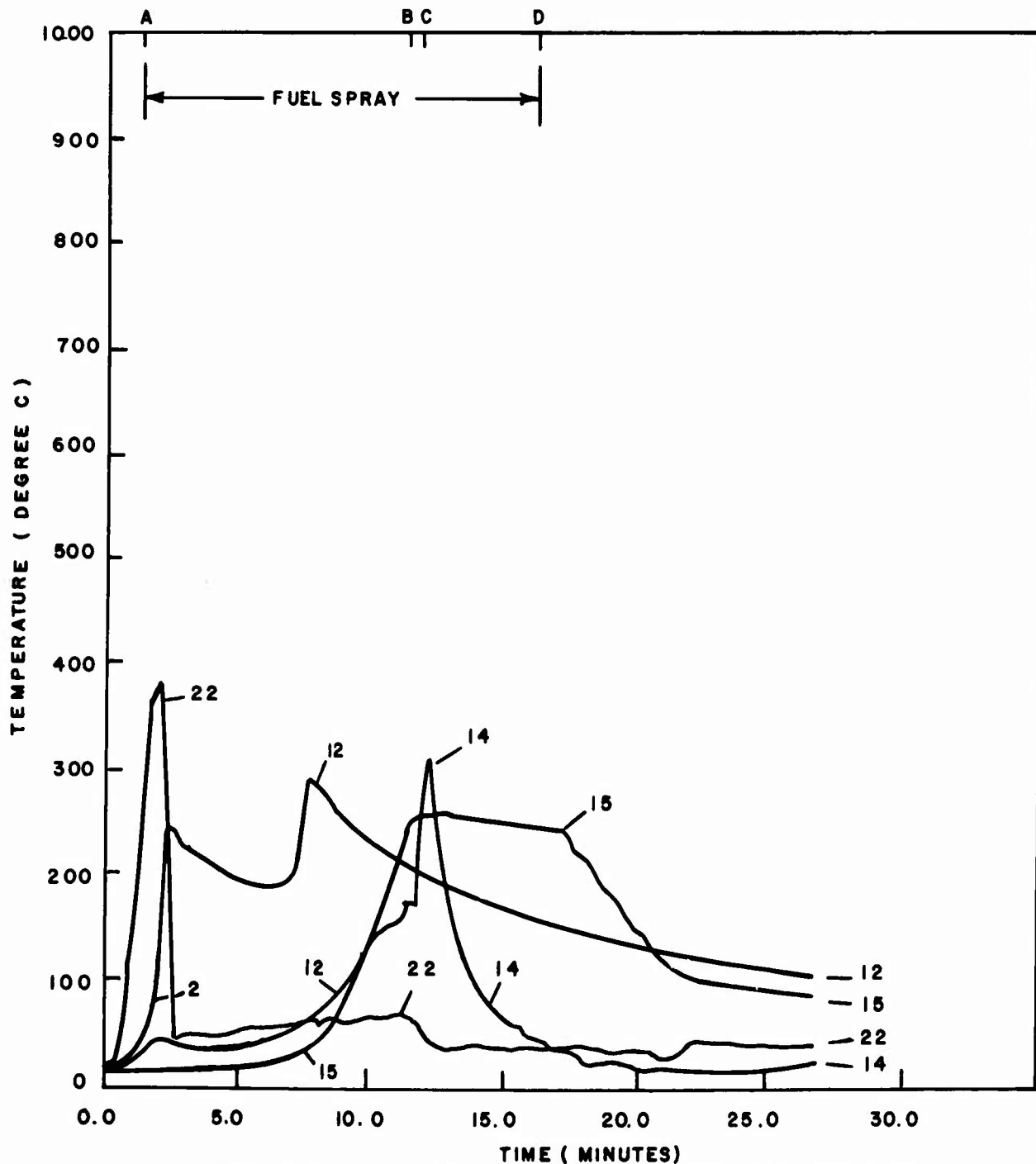


FIGURE 23 - TEST 6, TEMPERATURE VS TIME FOR THERMOCOUPLES 12, 14, 15, & 22.

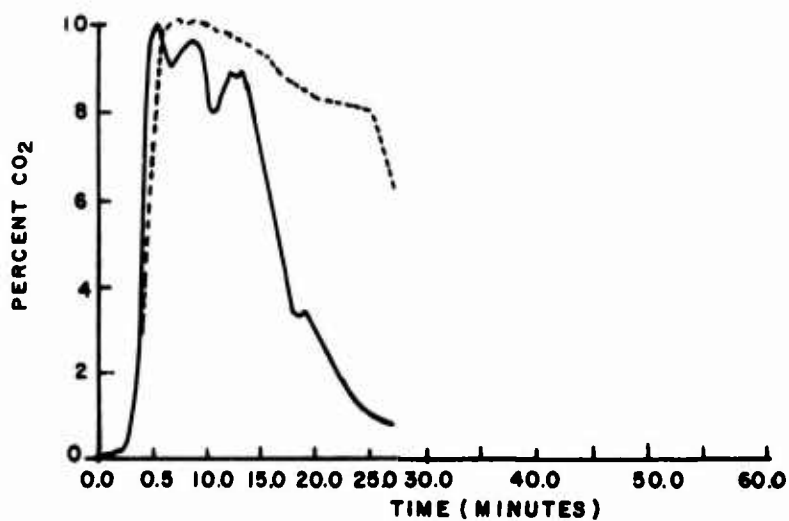
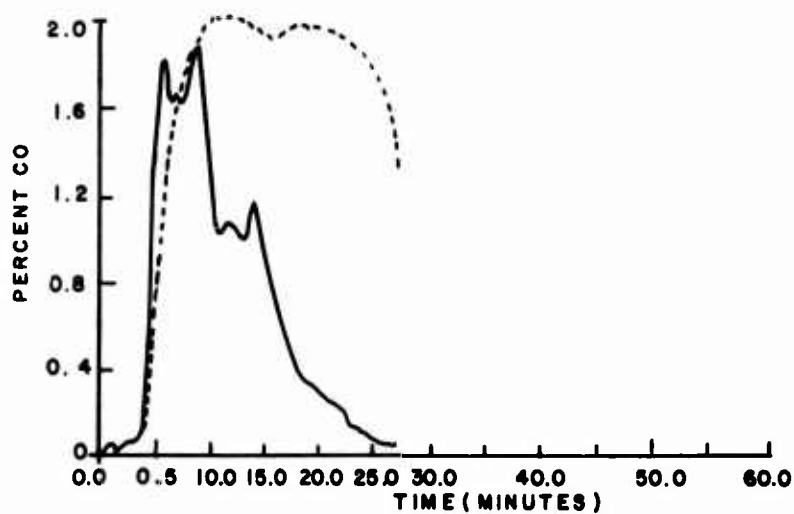
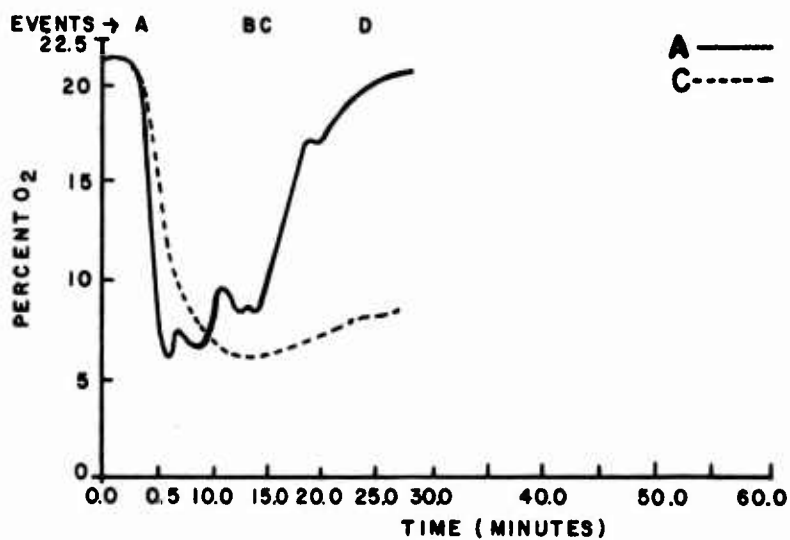


FIGURE 24 - GAS ANALYSIS, TEST NO.6

3.7 Test #7

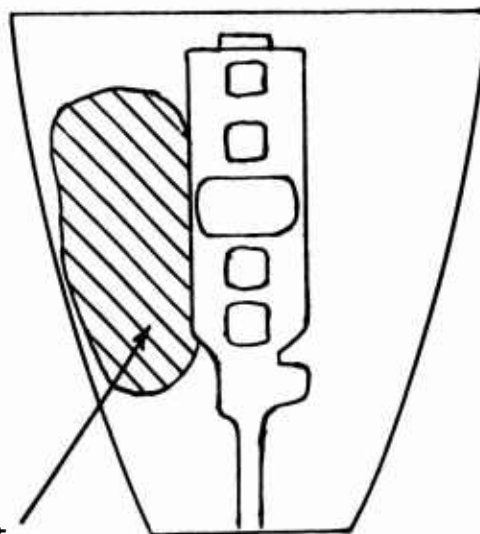
DESCRIPTION: One generator @ 100%
through skylight fwd

Test Date: 17 December 1974

Relative Humidity: 45%

Barometric Pressure: 763 mm Hg

Area of
Involvement



Machinery
Space

MAJOR EVENTS:

Time

- | | | |
|---|-------|-------------------------------------|
| a. Start ventilation blowers | 02:41 | |
| b. Blower shutdown | 12:21 | |
| c. Start foam generators
(end preburn) | 13:25 | Total extinguishment
time: 9:13* |
| d. Generator shutdown
(extinguishment) | 17:59 | |

FOAM APPLIED:

Gen, first attempt 10 gal. reg. \pm 1 gal.

*after reflash 12 gal. reg. \pm 1 gal.

Water pressure, 100 \pm 10 psig. Foam expansion ratio, 465 \pm 10

Application rate (average), 3.9 \pm 0.05

- 0.1 CFM/sq. ft.

VENTILATION:

Forced,

Open area, Aft vent (10 ft²) and 2 vent ducts (9 ft² each)

REMARKS: Reflash occurred. Foam reapplied between 28:26 and 33:05

*Time includes both attempts. Recording of data terminated at 23 mins.

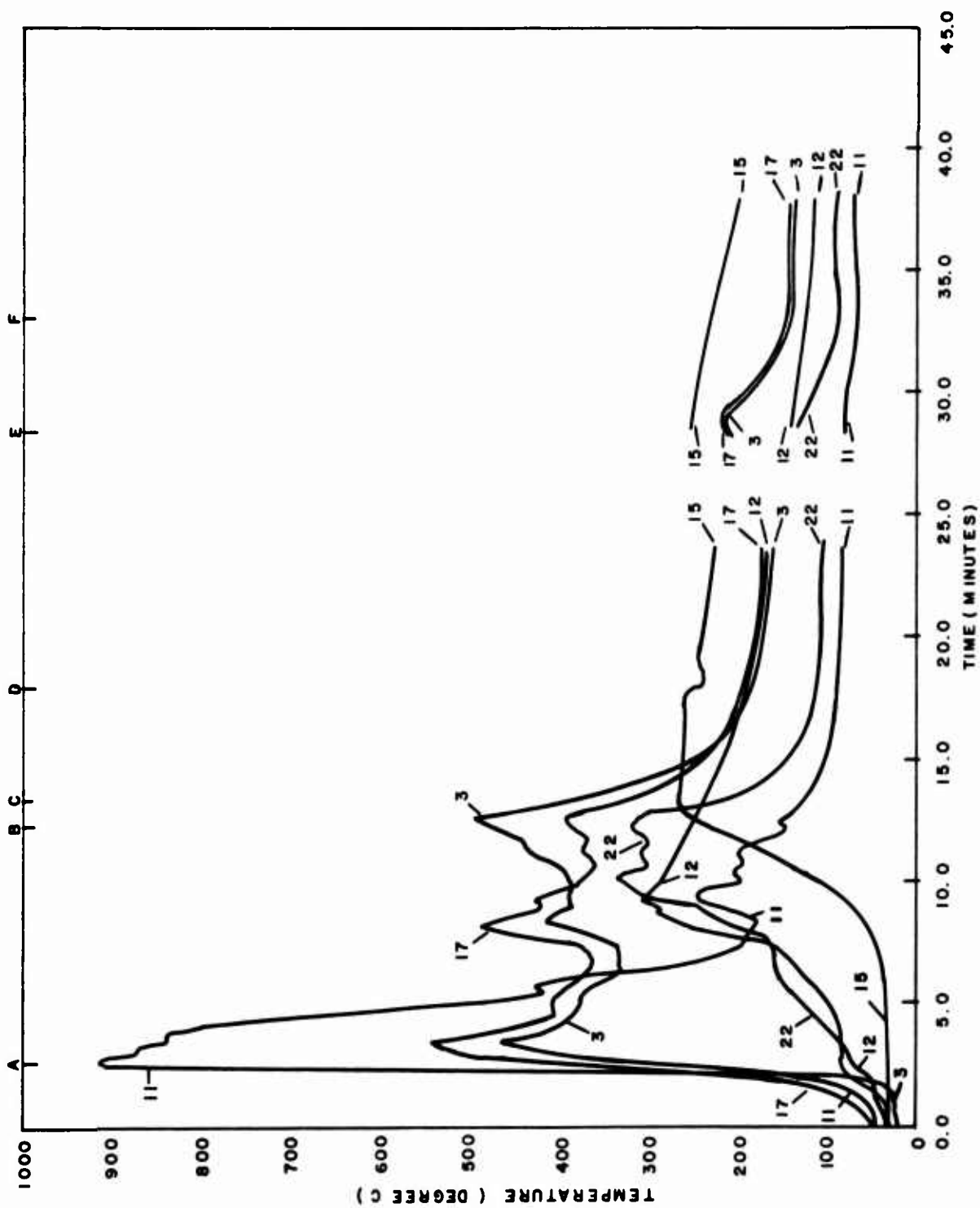


FIGURE 25 - TEST 7, TEMPERATURE VS TIME FOR
THERMOCOUPLES 3,11,12,15,17, & 2 2

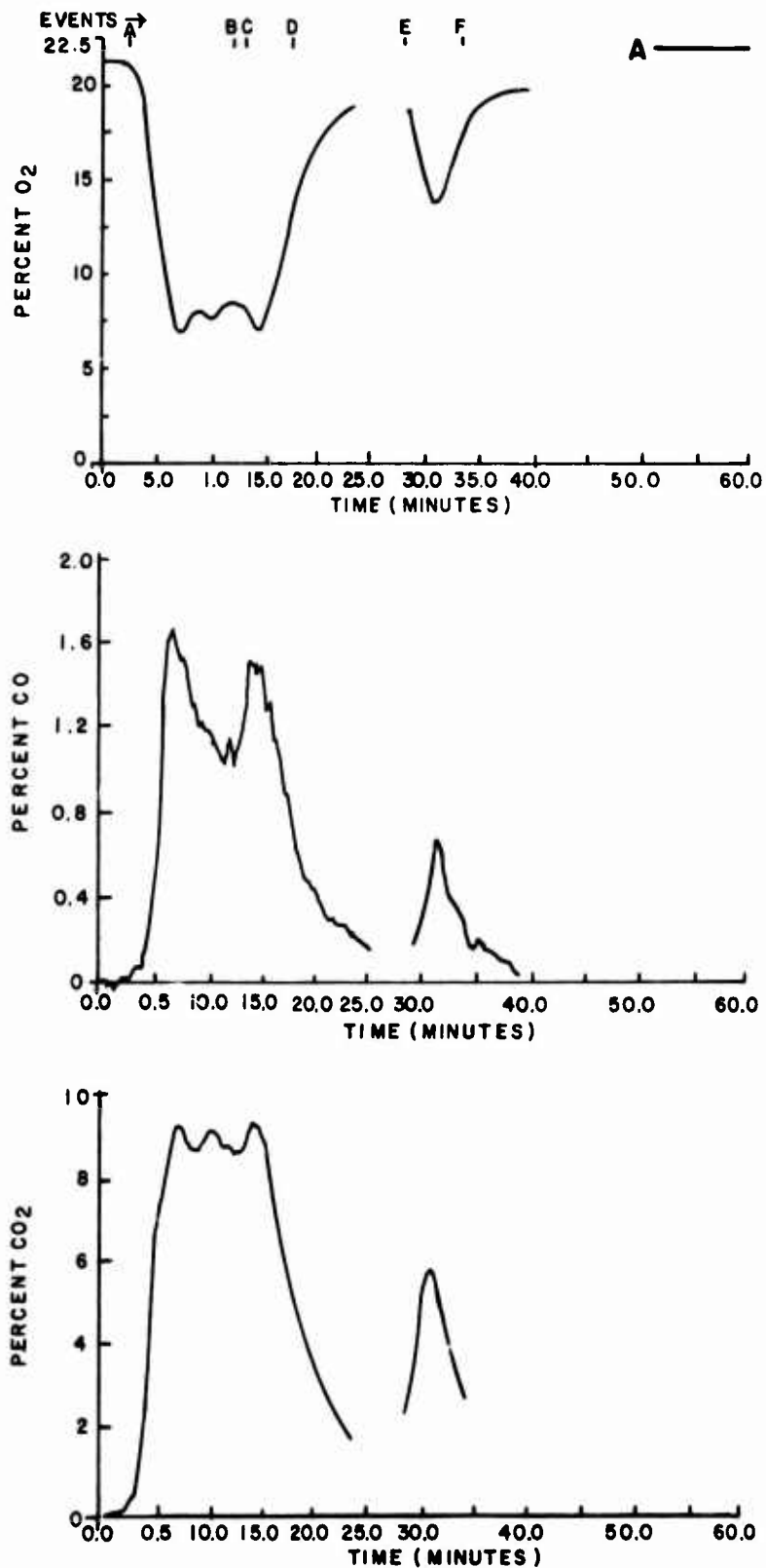


FIGURE 26 - GAS ANALYSIS, TEST NO.7

3.8 Test #8

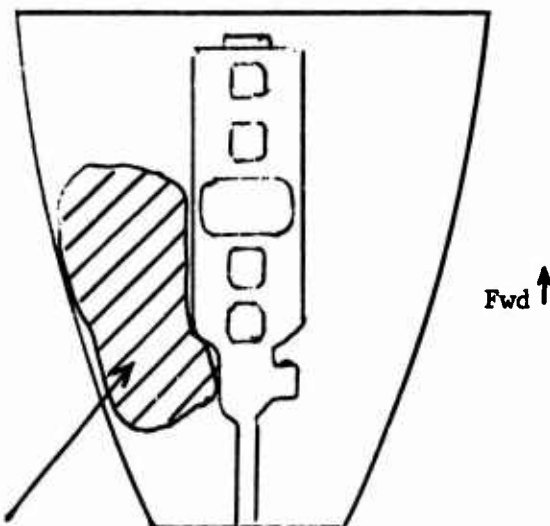
DESCRIPTION: Carbon dioxide extinguishment

Test Date: 17 December 1974

Relative Humidity: 38%

Barometric Pressure: 763 mm Hg

Area of
Involvement



Machinery
Space

MAJOR EVENTS:

Time

- | | | |
|--|-------|--|
| a. Start ventilation blowers | 01:28 | |
| b. Blower shutdown | 11:24 | |
| c. Release CO ₂
(end preburn) | 11:39 | Total extinguishment
time: 58 secs. |
| d. End CO ₂ discharge
(extinguishment) | 12:37 | |

QUANTITY OF CO₂: 2750 lbs.

Application rate (average), 47.4 lbs/sec.

VENTILATION:

Forced,
Open area, Aft vent (10 ft²) and 2 vent ducts (9 ft² each)

REMARKS: An immediate cooling was noticeable upon discharge of the CO₂.

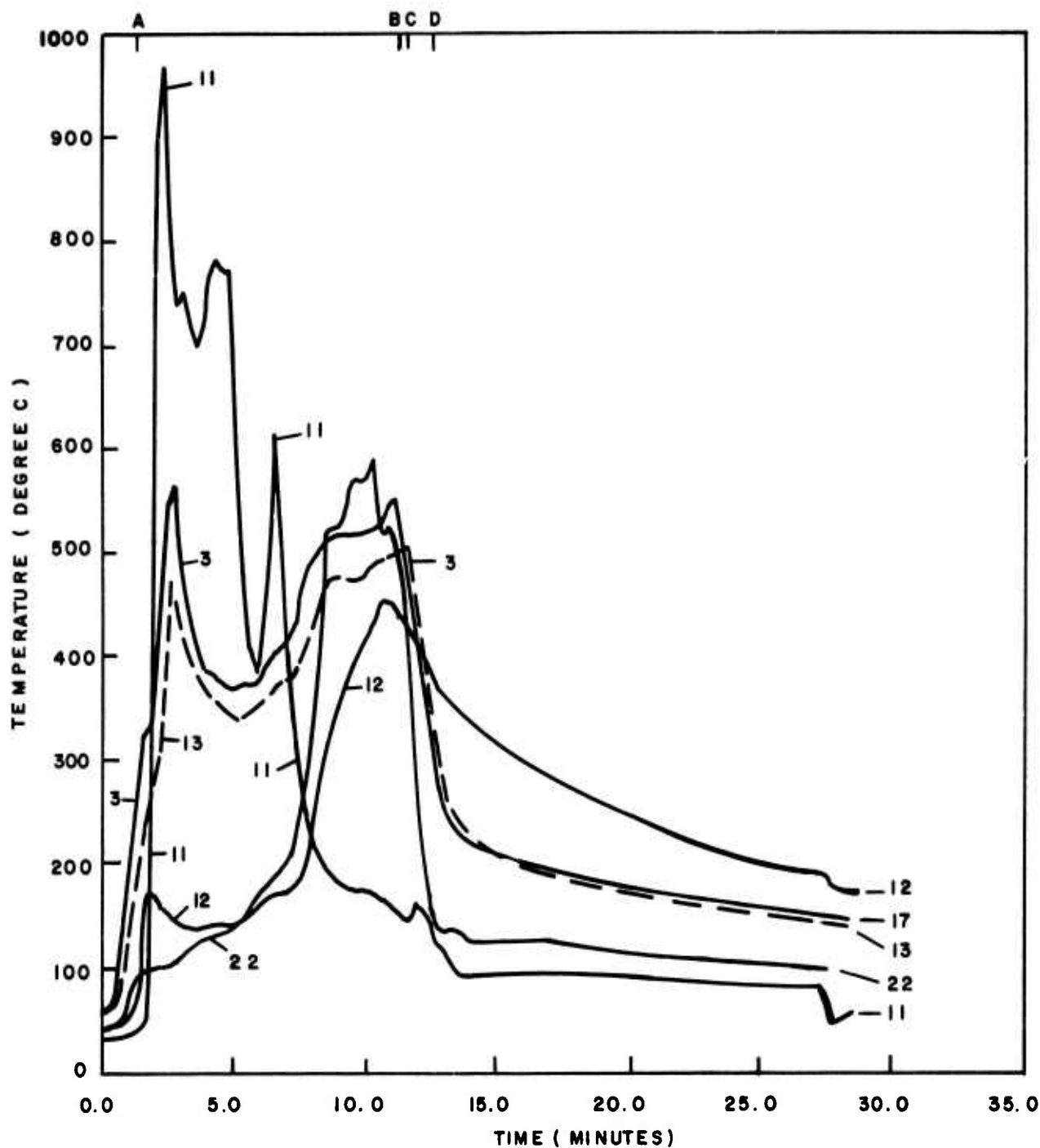


FIGURE 27 - TEST 8, TEMPERATURE VS TIME FOR THERMOCOUPLES 3, 11, 12, 17, & 22.

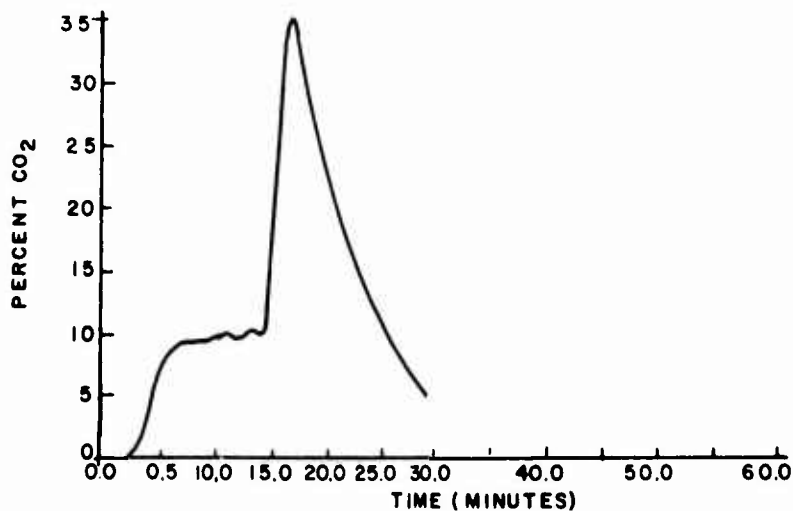
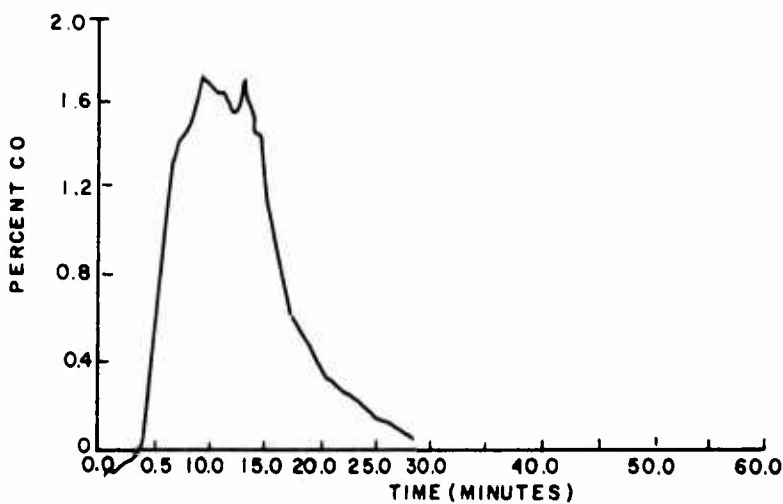
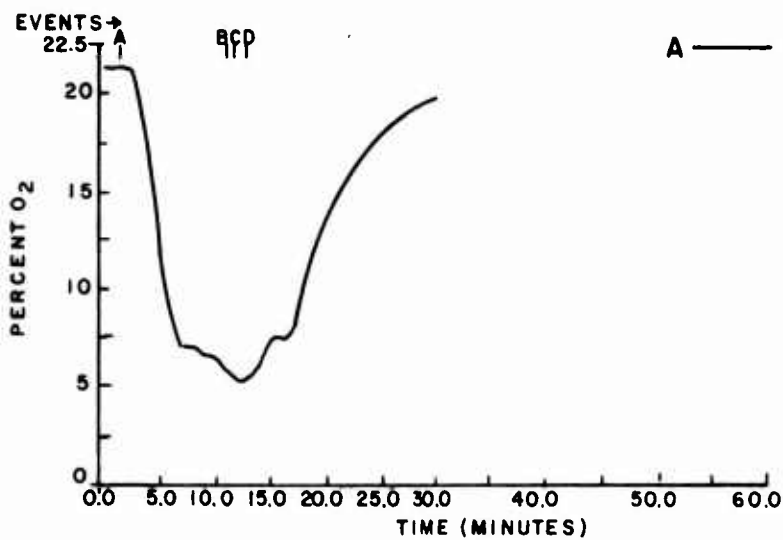


FIGURE 28—GAS ANALYSIS, TEST NO. 8

3.9 Test #9

This test was conducted to determine the high expansion foam fill rate of the machinery space without a fire. Two foam generators were used with 100 ± 10 psig inlet water pressure. They were installed in the same manner as in Test #1 and yielded an expansion ratio of 465 ± 10 at an average application rate of approximately 8 cubic feet of foam per minute per square foot. The results are plotted in Figure 29 as the foam height vs. time. There are three distinct phases to this curve with different fill rates as indicated.

3.10 Discussion of Results

One of the first concerns in analyzing this data is the fact that total fire involvement of the fuel's surface was never achieved. This can be readily observed by studying the area of involvement diagrams for each test. The three contributing factors to this result are in reverse order of significance; poor heat transfer into the fuel, the composition of the fuel; and oxygen starvation.

Poor heat transfer to the fuel is due to the relatively high mass of cold steel such as the engine block in direct contact with the fuel. This tends to act as a thermal sink and prevent the fuel from reaching its ignition temperature. Evidence of this is the fact that the second or third machinery space fire in a day tends to be more vigorous and produce higher temperatures faster than the first. It should be pointed out that the average temperature in the metal masses would be considerably higher on an operating ship.

The problem with the composition of the fuel was that the base layer of marine diesel was left over from a previous machinery space fire. Thus many of the low flash point derivatives were burned off and a much more "sluggish" fuel remained. While this was spiked with fresh marine diesel oil it is quite plausible that this new fuel remained with the vicinity of the fueling location. Thus a localized fire could be expected.

The most significant factor affecting the area of fire involvement is oxygen starvation of the fire. As the fire begins at the two ignition places it rapidly reaches the point where oxygen is being consumed from the entire volume of the machinery space. With the oxygen concentration thus reduced it would be difficult to maintain burning at adjacent areas of the fuel's surface. Thus, the fire changes from the fuel-controlled condition during the first few minutes to an oxygen-controlled condition in its later stages. This phenomenon can be observed by studying temperature and oxygen concentration histories of any of the tests presented. As an example, consider Test #1. The temperatures for this fire reach their peaks between 5 and 6 minutes from ignition as shown in Figures 10 and 11. During this same time interval the oxygen concentrations dropped well below 12 percent O_2 as shown in Figure 12. Thus it was during this time (i.e., between minute 5 and 6) that the machinery space fire progressed from fuel-controlled to oxygen-controlled. This phenomenon was observed during previous fires in the machinery space of the M/V RHODE ISLAND (References 3, 4 and 5).

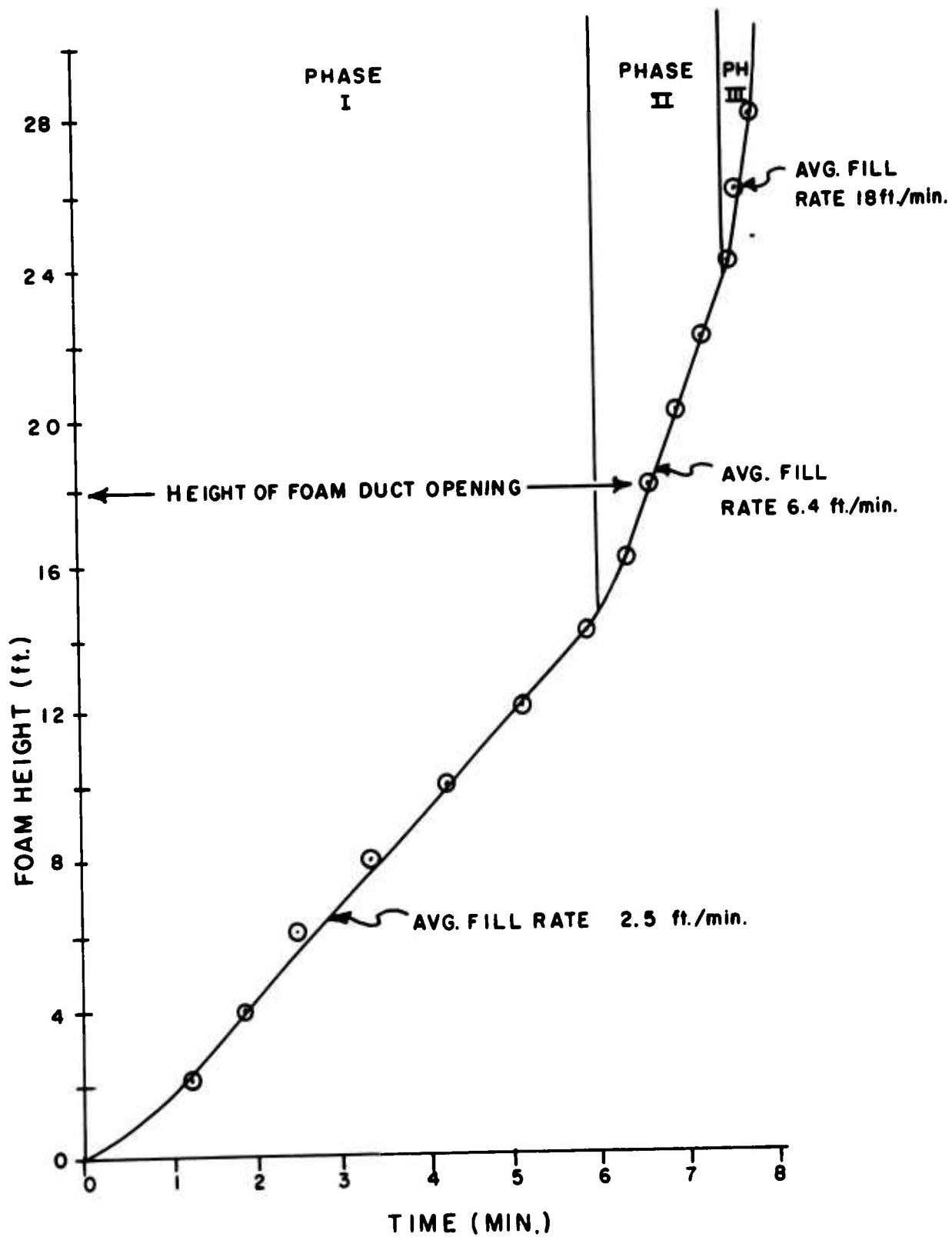


Figure 29. High expansion foam fill rate.

The oxygen starved fire with its reduced intensity in turn affects the heat transfer, and the slow volatilization of marine diesel fuel. Oxygen control occurs in such a short period of time that the total heat input into the machinery is low. Thus the fuel does not receive a significant heat transfer from the solid materials with which it comes into contact. Heat transfer from the fire gases over the fuel is not as efficient as metal to liquid heat transfer. Thus a major portion of the fuel is not heated enough to volatilize.

Varying the preburn time between 13 and 21 minutes produced no analyzable effects on the extinguishment times for Tests #1 through 4. It was, therefore, reduced to the shorter times for convenience in the remaining tests. Upon analysis of the data it is not surprising that this range of preburn times had little effect. All of the preburns carried the fire well into the oxygen-controlled stages. Even in the closest case (Test #4) preburn was ended and extinguishment was begun approximately 6 minutes after the lower temperatures and cyclical nature of an oxygen-controlled fire had set in.

The fuel spray employed in Test #6 had no noticeable effect on the extinguishment time. It did have an effect on the test fire as evidenced by the relatively large area of involvement and high temperatures. (See 3.6 and Figure 22.) This result is consistent with the known fire control capabilities of high expansion foam on these types of fires.⁶ It should also be noted that the port foam duct opening is located near the fuel spray nozzle.

While no empirical relationship can be deduced from the preburn, extinguishment time and application rate data taken, it can be seen that high expansion foam is capable of extinguishing oxygen-controlled machinery space fires. This should be further qualified to emphasize that the high expansion foam was made with outside clean air. The most rapid extinguishment was produced at the highest application rate (Test #2). It must be emphasized that the loose relationship between extinguishment time and application rate is due to the inherent problem in determining precisely when the fire has been extinguished as discussed in Section 3.0. The range of successful application rates was 3.9 to 7.9 cubic feet of foam per minute per square foot of fire area. This range is slightly higher than that required for successful extinguishment of flammable liquid spill fires which has been found to be 3 to 6 cubic feet of foam per minute per square foot of fire area.⁷ The difference is most likely due to foam losses during the application in a machinery space fire. This phenomenon will be discussed below.

The foam fill rate test conducted with no fire (Test #9) indicated three distinct filling phases. (See Figure 29.) Phase I is the average fill rate for the lower portion of the machinery space. This portion comprises the bulk of the volume as can be seen in Figures 1 and 2 and is also the area where the fire is actively engaged by the high expansion foam for successful extinguishment. The transition from Phase I to Phase II which occurs between the foam height of 15 and 17 feet is caused by two factors. First the cross-sectional area of the machinery space is reduced at these levels and secondly the height of the foam is approaching the foam duct openings. The significance of the latter fact is that the free-falling foam causes mechanical breakdown

of the existing foam blanket during Phase I but as the foam height approaches and finally passes the duct opening level this effect is reduced and finally eliminated. Thus the fill rate should increase as the duct opening level is reached because of a decrease in mechanical breakdown. Phase III of the fill rate curve is due exclusively to the further reduction in cross-sectional area of the space.

The testing indicates that it is possible to push high expansion foam down a ventilator shaft, against the updraft of fire gasses, in sufficient quantities to extinguish the fire. A typical example of the updraft of the fire gasses through the foam generation equipment during preburn is shown in Figure 8. A portion of the updraft depicted is due to the forced ventilation into the machinery space. The foam generation equipment was also capable of producing foam against a head of at least ten feet as measured in Test #9. (See Figure 29.) One important aspect of foam ducting which was not examined in this test series is the foam loss due to mechanical interaction with the surfaces of the duct. Some of the industry's data on this problem is provided in Appendix A.

Test #8 was conducted to provide a comparison test for CO₂ extinguishment of the same fire. The time recorded for CO₂ total extinguishment time is actually the total CO₂ discharge time. An examination of the temperature and gas concentration graphs (Figures 27 and 28) indicate that actual extinguishment took approximately 3 minutes. Thermocouples 11 and 22 measured rapid drops in temperature as the CO₂ was released. This is expected since they were low in the space and in the area where the CO₂ was released. Thermocouples 3 and 17 indicate a much slower drop in temperature and in fact did not get below 200°C for approximately 3 minutes. It should be mentioned that an entire discharge of the CO₂ supply as employed in this test would leave an operating ship without backup extinguishment capability which would be required in the event of a reflash.

4.0 CONCLUSIONS

High expansion foam is capable of extinguishing shipboard machinery space marine diesel fires when generated with outside air and in sufficient quantity. The required application rate (7 to 9 cfm/ft²) is somewhat higher than for high expansion foam extinguishment of open pool fires. There were no discernible effects due to expansion ratio over the range of 400:1 to 465:1 nor to vent area over the range of 18 to 36 square feet. The preburn times for all tests put the fires in the oxygen-controlled stages and had no significant effect on extinguishment.

Marine installation of high expansion foam systems should be designed to minimize the free fall of foam from the duct opening to the fuel's surface. Optimum designs would maintain this distance between the extremes of 6 and 12 feet thus permitting an adequate foam blanket while minimizing free fall of the foam. These installations should also take into account the foam to ducting mechanical interaction characteristics and the head of foam which the generation equipment can work into. They can also be used semi-portably. Their primary deficiency is that they require slightly longer to extinguish the fire.

APPENDIX A

MECHANICAL EFFECTS ON FOAM OUTPUT BY SHIELDING OR DUCTING

High expansion foam generators for flooding type fire control by design dispense foam from the periphery as well as the face of the generator screen. Because of this the installation of shielding or the insertion of the generator in a duct can measurably reduce the foam output by choking off the peripheral generation. To prevent this such shielding or ductwork must be at least 6" larger on a side or the radius than the generator.

With this spacing the foam loss is reduced to a percent or two. This loss is the mechanical interaction of the foam sliding against the duct or shield.

Where foam is forced for some distance through ducts of either metal or plastic the losses due to mechanical interaction can become severe. Test data in this area is not very reproducible due to the number of uncontrollable variables. In smooth straight metal ducts losses over 100 ft. of distance seldom exceed 15%. In plastic tubes which can fold or kink or in metal tubes with elbows or other interferences to foam flow losses can exceed 50% over 100 ft.

Losses are a function of drainage and expansion also. With slow draining foams (less than 50% in 20 minutes) and expansions in the 400 to 600:1 range losses as small as 30% have been experienced over 300 ft. distances in polyethylene tubes. With faster draining foams and/or higher expansions losses in excess of 60% have been experienced over 100 ft. distances with nylon tubes.

At present the data shows that for distances less than 50 ft., in ducts at least 6" larger on a side than the generator, and with slow draining foams of about 500:1 expansion, losses due to mechanical interaction are usually less than 15%, being lower for metal duct than for plastic tube.

REFERENCES

1. Kay, David. Design, Test and Evaluation of Total Coverage Fixed Fire Extinguishment System for Machinery Spaces. Naval Ship Engineering Center, 12 February 1973.
2. Alger, R. and Alvarez, N. The Destruction of High Expansion Fire Fighting Foam by the Components of Fuel Pyrolysis and Combustion. Naval Ordnance Laboratory, 29 July 1974.
3. Sheehan, Daniel F. An Investigation into the Effectiveness of Halon 1301 as an Extinguishing Agent for Shipboard Machinery Space Fires. U. S. Coast Guard Office of Research and Development, Washington, D.C., 10 March 1972.
4. Eberly, Randall. The Effectiveness of "Fire Gas Recirculation" Extinguishing Systems on Shipboard Machinery Space Fires. U. S. Coast Guard Office of Research and Development, Washington, D.C., June 1974.
5. Eberly, Randall. The Effectiveness of "Fire Gas Recirculation" Extinguishing Systems on Shipboard Machinery Space Fires. U. S. Coast Guard Office of Research and Development, Washington, D.C., January 1976.
6. National Fire Protection Association. Foam Extinguishing Systems, NFPA No. 11. Boston, Massachusetts, 1974.
7. Walter Kidde Company. Report on Fire Tests with High Expansion Foam on the QSTE Queen of Bermuda. Presented to English Board of Trade and Lloyds Register, Middlesex, England, March 1974.